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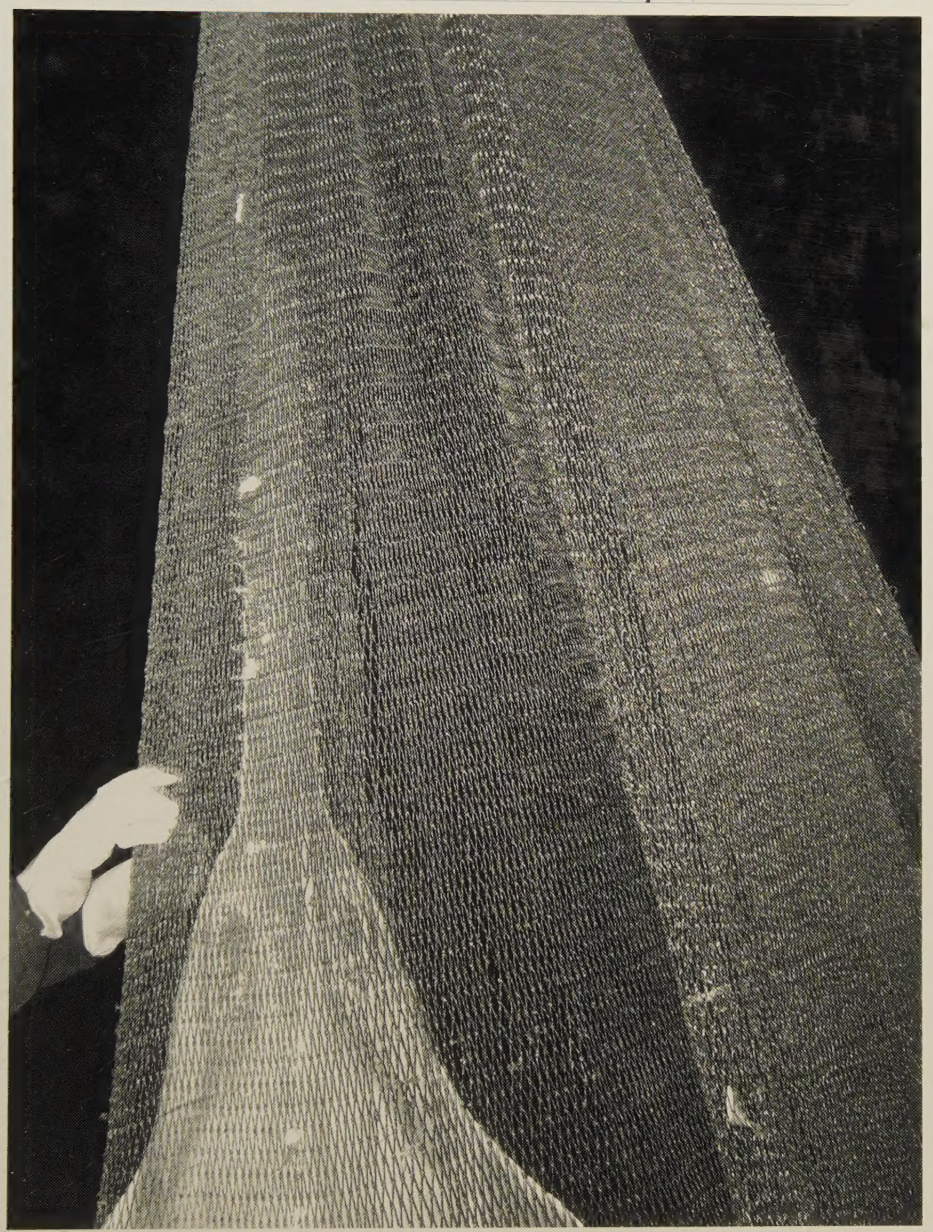

Sawtooth Sawfish Bycatch

Marine Fisheries REVIEW

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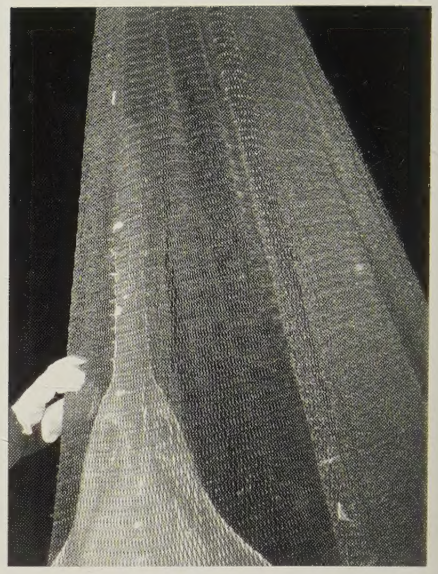

On the cover:
A smalltooth sawfish, *Pristis pectinata*, captured by an otter trawl net off of the Florida Keys. This mature male was documented by an onboard fisheries observer and quickly released by the crew (photo: NOAA/NMFS)

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Development of Video Electronic Monitoring Systems to Record Smalltooth Sawfish, *Pristis pectinata,* Interactions in the Shrimp Trawl Fisheries of the Southeastern United States, with Application to Other Protected Species and Large Bycatches

HEATHER E. MONCRIEF-COX, JOHN K. CARLSON, GREGORY S. NORRIS, MORGAN C. WEALTI, BETHANY M. DEACY, and ELIZABETH SCOTT-DENTON

Introduction

The use of electronic monitoring (EM) has the potential to augment the collection of bycatch information and lessen the need for onboard scientific observers, which in some cases can be very costly. Video technology can also be used on vessels that cannot take a human observer for safety reasons or vessel limitations. Since the late 1990's, various fisheries programs across the globe have explored the potential to extract specific information from video for management, with varying levels of success (Ames et al., 2007; Kindt-Larsen et al., 2012; Ruiz et al., 2015; Stanley et al., 2015; van Helmond et al., 2015, 2017; Bartholomew et al., 2018; van Helmond et al., 2019; Briand et al.[1]). Van Helmond et al. (2019) provides a comprehensive review of global EM projects and programs, including 12 fisheries that currently have some form of electronic monitoring as part of their regulatory process. Although EM is widely viewed as a way to improve monitoring programs, there is no standardized method of video data collection across fisheries. In fact, past studies have shown that the unique needs of individual fisheries must be assessed, as there is no overall single design possible due to varying vessel layouts, fishing practices, processing methods, catch biomass, and catch composition (Ruiz et al., 2015; van Helmond et al., 2019; Briand et al.[1]).

To date, there is not an EM program implemented in any shrimp trawl fishery across the globe; however, two pilot studies were previously conducted in Australia for prawn (Piasente et al.[2]). Even with similar targets and fishing practices, there are major differences in the sorting methods between the Australian and the United States (U.S.) southeastern shrimp fleets that have a major impact on EM system development. In Australia, cameras were set up over sorting conveyor belts, allowing for a more detailed view of the catch, as the animals are in a single layer (Piasente et al.[2]). This is not an option in the U.S. fleet, as

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[1]Briand, K., A. Bonnieux, W. Le Dantec, S. Le Couls, P. Bach, A. Maufroy, A. Relor-Stirnemann, P. Sabbaros, A. L. Vernet, F. Jehenne, and M. Goujon. 2018. Comparing electronic monitoring system with observer data for estimating non-target species and discards on French tropical tuna purse seine vessels. Collect. Vol. Sci. Pap. ICCAT, 74(6):3813–3831 (avail. at https://www.iotc.org/sites/default/files/documents/2018/09/IOTC-2018-WPEB14-18-Rev_1.pdf).

[2]Piasente, M., B. Stanley, and S. Hall. 2012. Assessing discards using onboard electronic monitoring in the northern prawn fishery. FRDC Project 2009/076. Aust. Fish. Manag. Auth., 59 p. (avail. at https://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2009-076-DLD.pdf).

ABSTRACT—The National Marine Fisheries Service (NMFS) began placing at-sea observers on commercial shrimping (Penaeidae and Sicyonia brevirostris*) vessels in the early 1990's in the southeastern region of the United States (U.S.) to identify and minimize the impacts of shrimp trawling on federally managed species. Recent analysis of bycatch data relative to smalltooth sawfish,* Pristis pectinata, *a species endangered globally, indicated a high level of uncertainty in the estimated take in the U.S. Due to costs associated with observer coverage, and given the rare event of capturing a smalltooth sawfish, increasing observer coverage to refine take estimates of this species is not considered practical. We explored the use of electronic monitoring (EM) to provide a valid alternative to increased observer coverage for the purpose of documenting fishery interactions with smalltooth sawfish. This system was additionally used to document interactions with other protected species and large teleost and elasmobranch bycatches (>1.0 kg). While no smalltooth sawfish were observed, the catch and safe release of a loggerhead sea turtle, Caretta caretta, was recorded by both the EM system and observer. The EM system was used to record commercial shrimp vessel operations during six trips, encompassing 1,733 h of video over 94 sea days, with a certified fishery observer also being present for the full duration of each trip. Catch composition documented by the EM reviewer was compared to observer data. Overall, 20 tows contained a total of 33 bycatch items in the observer sample that met criteria of being over 1.0 kg. Of these catch items, 87.9% were also detected by the EM reviewer compared to observer data. Detection rates for elasmobranchs were higher in comparison to teleosts, at 95.8%. Pairwise comparison of EM video to data collected by onboard observers (animals >1.0 kg in size) lead us to conclude that EM would be an effective tool for detecting protected resources and larger fauna interactions in the Gulf of Mexico shrimp trawl fishery.*

all catch sorting occurs on deck, with no conveyors or processing rooms, although small vessels may use a sorting table. This difference alone highlights the need for individual fleet studies for determining the most appropriate EM system model.

The exploration of EM in trawl fisheries is approached with caution, as they involve a high amount of catch in relatively short periods of time, and discerning catch composition can be highly problematic for this reason (Ruiz et al., 2015; van Helmond et al., 2015). Applicability of EM to shrimp trawls in particular is potentially even more problematic, as they target animals with low biomass, making it difficult to identify, measure, and count individuals, which are common goals of monitoring programs (van Helmond et al., 2015, 2017, 2019). However, the use of EM in shrimp trawl fisheries as a whole cannot be discounted, as it can improve monitoring in other manners, such as determining fishing pressure hotspots, vessel compliance, and bycatch interactions (Stanley et al., 2011).

In the southeastern U.S. commercial shrimp trawl fishery, vessels began voluntarily carrying at-sea observers in 1992, deployed by the National Marine Fisheries Service (NMFS) Galveston Laboratory (Scott-Denton et al., 2012; 2020). Mandatory coverage commenced in 2007 for the Gulf of Mexico, and 2008 for the U.S. southeastern Atlantic coast, hereafter referred to as the South Atlantic (Scott-Denton et al., 2012; 2020). Within the fishery, four species are targeted, three penaeid shrimps: white, *Litopenaeus setiferus;* brown, *Farfantepenaeus aztecus;* and pink, *Farfantepenaeus duorarum;* as well as rock shrimp, *Sicyonia brevirostris.* Currently, there are 1,420 vessels federally-permitted in the U.S. to harvest shrimp in the Gulf of Mexico, while the South Atlantic has 481 and 215 permitted vessels for penaeid (*Penaeidae*) and rock shrimp, respectively (Scott-Denton et al., 2012; 2020; SERO[3]). Detailed information on the U.S. southeastern shrimp fleet operations and effort can be found in Scott-Denton et al. (2012; 2020).

NMFS implemented observer coverage in this fishery to quantify finfish bycatch spatially and temporally, notably red snapper, *Lutjanus campechanus,* as well as to document and monitor shrimp trawl interactions with protected resources. Protected resources are species that are listed under the U.S. Endangered Species Act (ESA), the Migratory Bird Treaty Act, or the Marine Mammal Protection Act. These animals may be encountered as bycatch, and include five species of sea turtles (Kemp's ridley, *Lepidochelys kempii;* leatherback, *Dermochelys coriacea;* hawksbill, *Eretmochelys imbricata;* loggerhead, *Caretta caretta;* and green, *Chelonia mydas*); Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*; Gulf sturgeon, *Acipenser oxyrinchus desotoi;* and smalltooth sawfish, *Pristis pectinata* (Scott-Denton et al., 2012; 2020). Seabirds and marine mammal classifications cover a variety of families and genera, with all being protected through their respective Acts.

NMFS has undertaken several ESA section 7 consultations to address the effects of the southeast shrimp trawl fishery on protected resources that are listed as either threatened or endangered (NMFS[4]). Accurate estimates of fisheries take and mortality of sea turtles, sturgeon, seabirds, marine mammals, and smalltooth sawfish are critical to these consultations. Presently, data collected by onboard observers represents the most accurate and complete source for this information. However, despite this need, observer coverage of the entire southeastern shrimp fishery is about 2% of the total reported effort (Scott-Denton et al., 2012; 2020).

On 9 March 2010, the NMFS Southeast Regional Office requested to reinitiate section 7 consultation of the Endangered Species Act on the southeastern shrimp fishery to address new information indicating that the 2006 Incidental Take Statement (ITS) of smalltooth sawfish was exceeded. The biological opinion indicated annual sawfish take estimates to be 79.8 captures annually, based on combined effort across areas (Gulf and South Atlantic) and years (2008 and 2009) (NMFS[4]; Carlson and Scott-Denton[5]). However, the rarity of sawfish captures combined with low levels of observer coverage resulted in high levels of uncertainty in this estimate, with annual captures potentially as low as 16.88 or as high as 162.72 (Carlson and Scott-Denton[5]).

Concurrent with estimates of the levels of incidental take in commercial fishing gear is the need to estimate levels of observer coverage necessary to observe an interaction with a high level of precision, with a coefficient of variation (CV) of 30% generally recommended. Using the probability of a sawfish capture and an estimate of total shrimp effort in the eastern Gulf of Mexico, sample size estimates required to observe a smalltooth sawfish with a CV=0.3 was calculated at 11,380 tow h/yr (Carlson and Scott-Denton[5]). Applying the current average cost per sea day results in a cost over $1,000,000 to increase observer coverage in the eastern Gulf of Mexico. Intuitively, lower CV levels will incur higher observer costs due to higher sampling fractions, and higher CV levels would be less cost prohibitive. In light of the costs associated with ob-

[3]SERO. 2018. Fishery permits. Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (avail. at https://sero.nmfs.noaa.gov/operations_management_information_services/constituency_services_branch/freedom_of_information_act/common_foia/index.html).

[4]NMFS. 2014. Reinitiation of Endangered Species Act (ESA) Section 7 Consultation on the continued implementation of the sea turtle conservation regulations under the ESA and the continued authorization of the Southeast U.S. shrimp fisheries in federal waters under the Magnuson-Stevens Fishery Management and Conservation Act (MSFMCA). Consultation No. SER-2013-12255. Southeast Reg. Off. Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (avail. at https://sero.nmfs.noaa.gov/protected_resources/section_7/freq_biop/documents/fisheries_bo/shrimp_biop_2014.pdf).

[5]Carlson, J., and E. Scott-Denton. 2011. Estimated incidental take of smalltooth sawfish (Pristis pectinata) and an assessment of observer coverage required in the South Atlantic and Gulf of Mexico shrimp trawl fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Panama City, Fla., SFD Contribution PCB-11-08, 15 p.

server coverage and the low frequency of capturing a smalltooth sawfish, increasing observer coverage may not be the most practical solution for refining the take estimates of this species (Carlson and Scott-Denton[5]). EM was suggested as an alternative for addressing the data gap at lower costs, but an effective monitoring system needed to be developed for this fishery (Carlson and Scott-Denton[5]).

Given the large size of these animals, video monitoring would have the capability to record them either entangled in the net itself, entrapped on bycatch mitigation tools (turtle excluder devices (TED's)), or on deck when catch is emptied from the net. Herein, we report a study to test electronic video monitoring hardware, software, and review protocols to determine the feasibility and reliability of the method for bycatch interaction monitoring within a shrimp trawl fishery. In partnership with the southeastern U.S. shrimp trawl industry, this pilot study sought to determine if 1) EM hardware system design is capable of maintaining high-quality operating standards in variable environmental conditions encountered at sea, 2) EM video can provide images of sufficient resolution and clarity to allow a video analyst to accurately account for smalltooth sawfish and other large bycatch interactions, 3) EM video is able to provide images of sufficient resolution and clarity to allow a video analyst to identify animals at the species level, and 4) results from video monitoring are similar to those obtained from onboard observers.

Methods

Onboard observers documented vessel and gear characteristics, tow information, and catch composition on all tows as described in Scott-Denton et al. (2012; 2020). Net characteristics, including those of the trawl body, cod end, and doors, along with TED's and bycatch reduction devices (BRD's) were recorded. Measurements of the try net, a separate, smaller net used by fishermen to evaluate catch composition throughout a tow, were also taken.

Each tow consisted of four main nets being pulled adjacent to one another behind the vessel, in addition to the try net, which was towed in front of one of the interior nets. Once a tow was complete and the nets were brought back to the vessel, the observer ensured that the catch of the two exterior nets ("outboard nets") was kept separate from each other and from the catch of the two interior nets. Any rare or large animals caught in each outboard net that could affect the catch characterization process were selected from the pile (i.e. no extrapolation was required), counted, and weighed by species (Scott-Denton et al., 2012; 2020).

The observer subsampled each outboard net by filling a shrimp basket with a mixed portion of its catch. This subsample basket was weighed prior to the contents being sorted into defined categories, including white, brown, or pink shrimp, crustaceans, teleosts, debris, and individual species of priority fishes ("characterization"). Certain categories of animals were counted, and all designated groupings weighed separately, following the protocol in Scott-Denton et al. (2012; 2020). This characterization of the sample basket, along with the selected weights from rare or larger animals, was used to determine the entire net's catch through extrapolation, as detailed in Scott-Denton et al. (2012; 2020). This process was repeated for up to two outboard nets per tow throughout the duration of the trip (Scott-Denton et al., 2012; 2020).

During a typical tow, the try net was deployed and retrieved multiple times, and being the only net typically exempted from having both a TED and BRD present, it had the potential to allow for higher catches of bycatch species, including protected resources (Scott-Denton et al., 2012). Observers did not characterize catch within a try net; however, they measured, sampled, and documented any incidental captures with all U.S. federally protected species. Once the trip was complete, all observer data was sent to the NMFS Galveston Laboratory, where it was housed, managed, and archived, following a trip debriefing session with an observer coordinator.

The Southeast Fisheries Science Center (SEFSC) contracted with Saltwater Inc.[6] to develop, install, and monitor an EM system on two vessels selected for the study. The EM system was comprised of a control box, four internet protocol (IP) cameras, a rotation sensor ("sensor"), GPS receiver, keyboard, and a monitor. Other than the sensor and cameras, the entire system was installed in the wheelhouse of each vessel and was roughly 0.5 m^2 in size. The monitor allowed the user to see, in real-time, the status of the sensor, position of the vessel, data storage status, whether or not the system was recording, and what was being recorded.

The control box was equipped with open-source software[7] and two hard-drive bays with removable 2 terabyte drives that stored all video and sensor data during each trip. The sensor was mounted on the winch of the fishing vessel, and when the winch was activated to set and haul the gear, the sensor sent a reading back to the control box. Sensor output was read by the onboard software, which determined if the vessel engaged in fishing activity. Since the retrieval of the try net does not utilize the same winch as the main nets, the system was set to record continuously, as long as it had power, to capture these events. Sensor data for hauling of the main nets allowed the reviewer to more quickly and efficiently identify fishing events and other data.

When the system was initially installed on the vessels, EM technicians consulted with vessel operators to determine the best positions for the four cameras so that all pertinent fishing data could be captured. Two cameras were focused on the gear as it was set and retrieved, one at port and one at starboard. Two other cameras were

[6]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[7]Accessed via written request to Saltwater Inc., 733 N. St. Anchorage, AK 99501.

Table 1.—Counts of specimens > 1.0 kg documented by observer compared to EM reviewer at species level, split by classification.

Common name	Scientific name	Observer	EM	Detection rate
Atlantic guitarfish	*Rhinobatos lentiginosus*	1	1	1
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	8	7	0.875
Blacktip shark	*Carcharhinus limbatus*	6	6	1
Bonnethead shark	*Sphyrna tiburo*	2	2	1
Finetooth shark	*Carcharhinus isodon*	2	2	1
Smooth butterfly ray	*Gymnura micrura*	2	2	1
Smooth dogfish	*Mustelus canis*	3	3	1
	Total elasmobranchs	24	23	0.9583
Lane snapper	*Lutjanus synagris*	2	0	0
Red drum	*Sciaenops ocellatus*	1	1	1
Red snapper	*Lutjanus campechanus*	4	3	0.75
Southern flounder	*Paralichthys lethostigma*	1	1	1
	Total teleosts	8	5	0.6250
Loggerhead sea turtle	*Caretta caretta*	1	1	1
	Total protected resources	1	1	1
Total specimens		33	29	0.879

installed to monitor the catch as it was being processed, with one camera focused on the sorting area, and the other at a scupper for observation of discarded bycatch. The two cameras pointed toward the gear were set to record at 360p (480 x 360 pixels) and 10 frames per second. This setting allowed the reviewer to identify larger catch items in the nets upon retrieval without using excessive space on the hard drives. The sorting and scupper cameras were set to 1,080p (1,920 x 1,080 pixels) at 10 frames per second so that the reviewer would be able to better identify the catch as it was being separated on deck.

At the end of a trip, hard drives were returned to Saltwater Inc. for video assessment and catch documentation. Personnel that reviewed the videos were current or prior at-sea observers, and therefore trained in the use of taxonomic keys and other methodologies for identifying species to the lowest taxonomic level possible. Reviewers were given an overview of the data collection protocols used by the onboard observers, as well as an overview of common fishing practices used by the U.S. shrimp fishing fleet to ensure a complete understanding of the activities documented in the videos. Each tow was identified by the reviewers based on the data from the rotation sensor, and video was reviewed from the time the net winch started the gear haul back to the time the crew finished sorting catch on deck. When larger bycatch animals were seen in the outboard nets, reviewers documented the time, location, and species identification, in addition to taking screenshots and relevant notes. Video was also analyzed for all try net tow catch emptied on deck. Reviewers prepared a trip summary report for each trip that included total sea days, video hours, review hours, number of tows, and comments on other identifiable species, protected resource interactions, and other pertinent notes. All reviewer data underwent a proofing and debriefing process with the EM review team at Saltwater Inc.

After completion of all debriefings, the observer data and the EM video data were compared and evaluated for the capture of a sawfish during a tow. In the absence of a sawfish or other protected species (e.g., sea turtle), EM data was compared to observer data to see if the reviewer annotated the animals documented by the observer as being >1.0 kg in weight. This value was determined to be sufficient for comparison of a "typical" large bycatch species by EM reviewers and SEFSC staff. Weight was chosen over length because observers only record lengths for red snapper, and protected resources, whereas all weights were present for characterized catch.

In cases where multiple animals of the same species in a net were weighed together (n=5), whether selected directly or as part of the characterization process, an average weight was calculated to validate that criteria were met. Following Ruiz et al. (2015), observer data were treated as the independent sample for analysis, while EM data was associated with potential statistical error. Detection rates were determined by dividing observer data by that of the EM reviewer for each species, as well as by classification category (Table 1).

Results

The EM hardware operated for the duration of the trips with no water ingress to the deck components, and there was only one significant gap that may have been caused by a system component malfunction. Minor issues encountered, such as water droplets affecting view and damaged wires, were manageable by vessel operators at sea or EM technicians in a single shore visit. Overall camera framing of the towing activity for the project was well placed and documented all major areas of the vessel in which there was normal fishing activity. Reviewers were able to see the nets as they were brought alongside the vessel, as they came out of the water, and as they were brought onto the deck where they were emptied and sorted.

Examination of the observed trips took approximately 181 hours to eval-

Table 2.—Individual trip information.

Vessel	Trip	Sea days	Tows	Total video (h)	Review time (h)
1	1	22	43	453	41
1	2[1]	16[1]	27[1]	0[1]	0[1]
1	3	14	21	268	24
1	4	20	38	298	30
2	1	8	13	161	15
2	2	13	25	253	32
2	3	17	29	300	39
Total Recorded	6	94	169	1,733	181

[1]Trip in which video was lost in shipping process due to hurricane; Sea Days and Tows values excluded from Total Recorded.

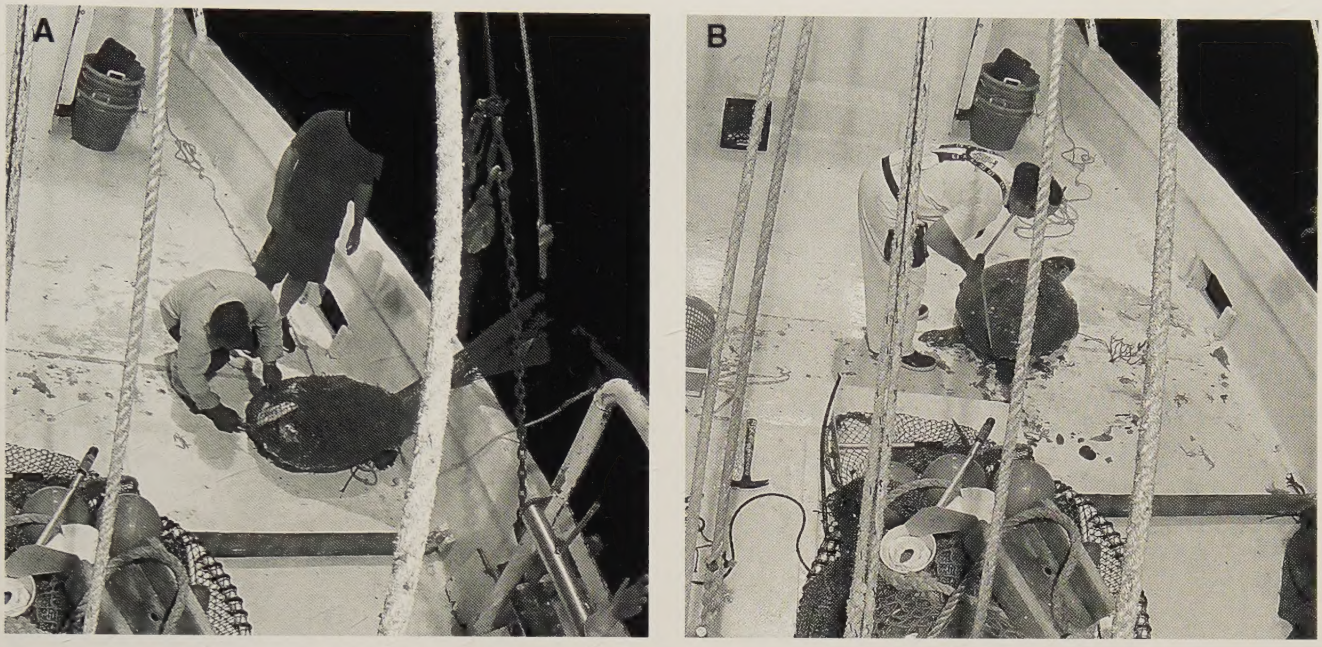

Figure 1.—Loggerhead sea turtle, *Caretta caretta,* A) brought on board in try net. B) being measured by observer prior to release.

uate 1,733 hours of video (Table 2). A total of 94 observed sea days were recorded, consisting of 169 tows (Table 2). No smalltooth sawfish were captured during the pilot study, and therefore no comparisons could be made for this species. A single loggerhead sea turtle captured in a try net was documented by both the observer and EM reviewer (Fig. 1, Table 1).

EM reviewers were able to identify many animals to the species level, including those smaller than the 1.0 kg threshold, such as the presence of rock shrimp, tricorn batfish, *Zalieutes mcgintyi;* Atlantic bearded brotula, *Brotula barbata;* and calico box crab, *Hepatus epheliticus.* Even during periods of low light, the EM reviewer was able to detect and identify larger bycatch items such as sharks and rays (Fig. 2). The EM systems' performance quality allowed for accurate identification throughout the duration of the study period, April 2017 through March 2018.

During 19 tows, 32 bycatch specimens were recorded by the observer as being over 1.0 kg. The EM reviewer was able to identify 28 of these specimens, a detection rate of 87.5%. Of the animals missed by the EM reviewer, most were teleosts (n=3), with a detection rate of 62.5% (Table 1). For elasmobranchs, the detection rate was 95.8%, with a single Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, being undetected. Inclusion of the loggerhead sea turtle capture provides a total detection rate of 87.9% for 33 bycatch items. There were no situations in which the EM reviewer documented a greater number of large bycatch specimens than the observer in the compared data.

Discussion

The overall detection rate of 87.9% supports the use of EM for bycatch monitoring in the U.S. commercial shrimping fleet for large animals, including many protected resources. Sharks, rays, and sea turtles have exaggerated body shapes in comparison with bony fishes, potentially lending to higher observation levels by EM reviewers.

While teleosts were detected at a rate of 62.5%, it is anticipated that adjusted camera angles specific to vessels could improve this value. This rate was also credited to observer sorting methods by EM reviewers, a situation that would not arise on trips where an observer was not present. While the crew of a vessel sorts catch in a single, central area with catch spread on deck, observers tend to take their sample baskets to a corner of the vessel and sort straight into smaller baskets for the characterization, inhibiting view of individual items. The addition of a fifth camera at the stern of the vessel could assist in preventing this issue, while expanding overall coverage of the vessel. This lower rate can also be attributed to the higher variability caused by the small sample size obtained in this pilot study. The low number of large animals for quantitative comparison in this analysis was likely influenced by the use of BRD's and TED's, which decrease large bycatch specimens as intended.

Despite the high detection rate for larger species, electronic monitoring does have limitations and issues. For example, the electronic data for an additional observed trip was lost during shipping due to a hurricane, and therefore had to be excluded from analysis, resulting in a loss of approximately 290 hours of video. The only EM

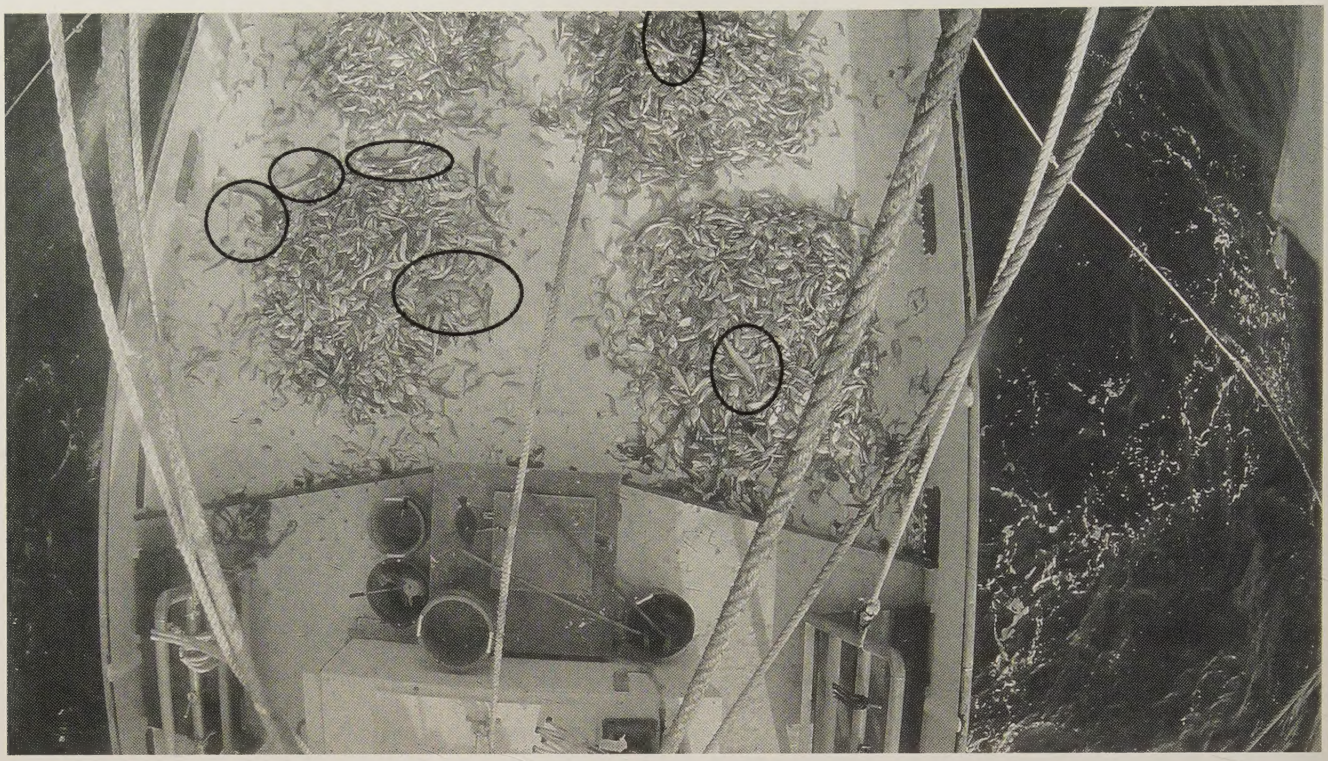

Figure 2.—Sharks documented with the EM system.

system performance issue of the study occurred during this trip, with a single camera having intermittent connectivity issues due to a damaged wire, which was fixed when the vessel returned to the dock. Since the electronic data was lost, we were not able to evaluate the impact this performance issue had on the data collection process. This occurrence shows a serious weakness of EM data collection, and future work would need to address this source of loss, whether it is electronic submission of the data while in port or duplication of hard drive data prior to shipping.

System malfunctions at sea from accidental damage or hardware tampering also need to be priorities when designing large-scale monitoring programs. These issues can be rectified once the vessel has returned to port, but investigation of remote repair options and incorporation of fines for monitoring equipment tampering should be considered. Limiting opportunities for data loss of any kind is necessary in future program development so that uncertainty in data quality is kept to a minimum.

While some discrepancies between the EM reviewer and observer were found, potential modifications could be implemented to correct these. For instance, tarps are often used to block the sun on many shrimp vessels to prevent reduction in the quality of the shrimp catch. This was recorded on one of the study vessels during an un-observed trip, so was able to be corrected without impacting the data (Fig. 3A). In this case, standard camera mounting was lowered so there was an unobstructed view of catch sorting (Fig. 3B). Camera placement on each vessel will vary, with no single standard able to cover all vessels due to catch processing procedures, as well as vessel size and layout differences. Future work should also consider placing fine resolution cameras more directly over the scupper holes in order to see discarded bycatch more clearly. However, obtaining a direct scupper view may be a challenge due to limited options for camera mounts and wire placements. Wires run across the deck are more frequently damaged by regular deck activities, and they can also be a safety hazard for the crew.

Goals in the development of an EM program for shrimp trawls should take into consideration opportunities for improvements to fisheries compliance, as well. An EM system can be used to determine if vessels are following gear regulations, by including the presence of TED's and BRD's in review criteria (Piasente et al.[2]). Also, determining a method in which catch weight can be estimated, such as by counting retained product containers as they are moved into the storage area at the end of a tow, is possible (Piasente et al.[2]).

Additionally, this study used software capable of only managing one rotation sensor, causing the entire trip duration to be recorded. This resulted in a higher amount of video, which increased review time, as well as stor-

age needs. Current software versions, however, are able to include multiple sensors, allowing for a second sensor to be placed on the try net, therefore marking those tow times in the EM video and improving monitoring of that net alone.

The availability of additional data collected by the EM system can be incorporated in further program development and evaluation. Although the EM system and review process were able to record large bycatch on all tows, the observer is obtaining a subsample, so only those animals documented by the observer could be compared for this analysis.

While EM could supplement low observer coverage rates, it does not replace onboard observers, who are able to collect different types of data (i.e., measurements and biological samples), and attach tracking tags to protected resources. EM can be used instead to validate observer data, improve data quality, and increase coverage rates and protected resource take estimates.

EM can bolster observer coverage by allowing for data verification both at sea and upon completion of a trip. In cases of a protected resources being returned to the water without visual confirmation and evaluation by the observer, video could be reviewed for documentation. Benefits of EM include the opportunity to review video as many times as needed, as well as to have more than one person identify questionable specimens.

Observers are less likely to witness all try net operations, as this will generally cause them to exceed safe working hours due to interrupting mandated sleep times. Having EM cameras recording this vital information has the potential to increase documentation of protected resource interactions, both with and without observers present.

It is most beneficial to an EM program that video reviewers are current or former observers for that specific fishery, as they will be the most familiar with the practices and species encountered of that fishery (Chavance et al.[8]). In future monitoring scenarios, a current observer can serve as a video reviewer when not deployed, such as in times of low fishing pressure due to weather or fishery closures. This will help maintain observer morale as they are kept employed continuously, while also being able to vary their work practices, which aids in employee retention and career satisfaction (van Helmond et al., 2019).

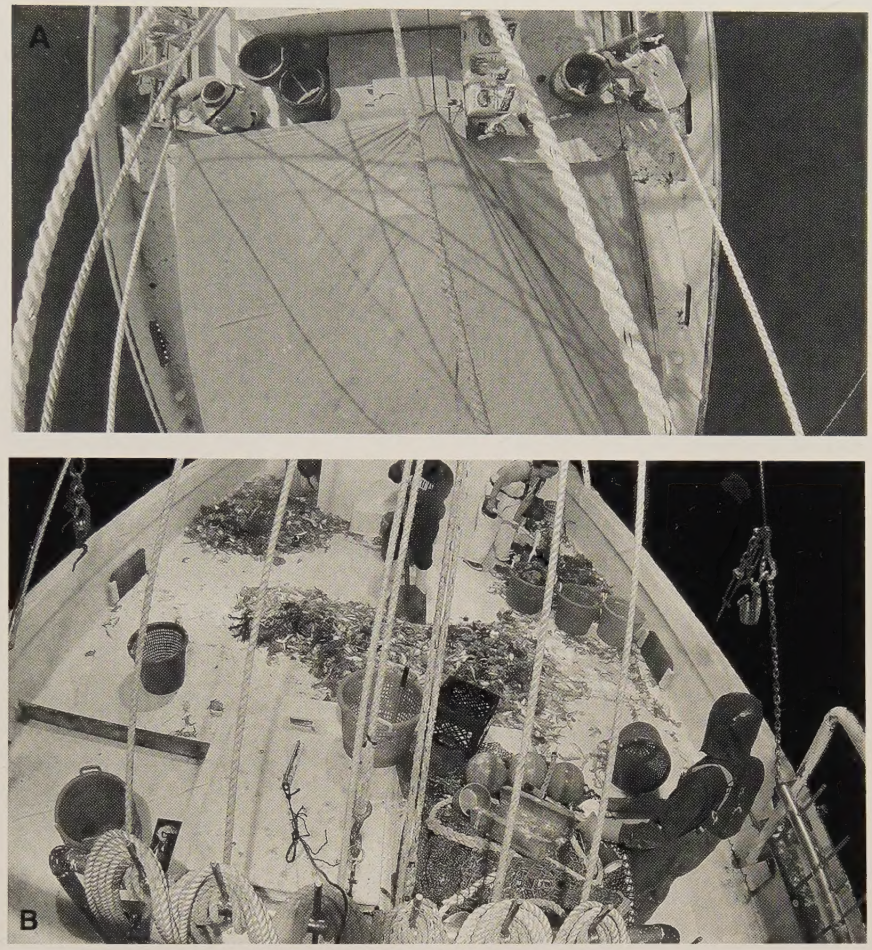

Figure 3.—Deck of vessel with A) tarp covering deck during sorting, inhibiting view, and B) adjusted view to prevent tarp from obscuring images.

The lack of capture of any smalltooth sawfish was expected, due to few specimens being observed in the program annually, if any. The majority of documented interactions in observer program history occurred in the same area where fishing effort took place in this pilot study (Scott-Denton et al., 2012; 2020). Smalltooth sawfish become quite large (≤ 5.18 m), have unique body shapes, and are sufficient in size at birth to be recorded with EM throughout their lifespan.

The accurate identification and documentation by the EM reviewer of the loggerhead sea turtle capture in the try net supports the use of EM for this and other sea turtle species once they reach sufficient size (> 1.0 kg). Sea

[8]Chavance, P., A. Batty, H. McElderry, L. Dubroca, O. Dewals, P. Cauquil, V. Restrepo, and L. Dagorn. 2013. Comparing observer data with video monitoring on a French purse seiner in the Indian Ocean. IOTC-2013-WPEB09-43, 18 p. (avail. at https://www.iotc.org/documents/comparing-observer-data-video-monitoring-french-purse-seiner-indian-ocean).

turtle bycatch in the shrimp trawl fleet has been a concern for many years, as this fishery historically had the highest number of interactions compared to any other U.S. fishery, at one point responsible for nearly 98% of sea turtle bycatch (Moore et al., 2009; Finkbeiner et al., 2011). Requiring TED's, including a larger escape opening size mandated in 2003, as well as a major fleet reduction since the early 2000's have greatly lowered these rates (Finkbeiner et al., 2011). Uncertainty in these bycatch rates and associated survivorship values caused by low observer coverage levels has raised the suggestion of incorporating electronic monitoring for these species as well, and our pilot study may present a valid model for future testing (Moore et al., 2009).

Filling in these types of data gaps provides opportunity for improved take estimates of protected species bycatch through increased observations of fishing efforts, greatly strengthening our fisheries management processes in the U.S. shrimping fleet of the Gulf of Mexico and South Atlantic.

Acknowledgments

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Seasonal Occurrence of Cetaceans along the Washington Coast from Passive Acoustic Monitoring

CANDICE K. EMMONS, M. BRADLEY HANSON, and MARC O. LAMMERS

Introduction

Estimates of cetacean abundance, density, and distribution are necessary to understand the role of cetaceans in marine ecosystems and to identify potential anthropogenic threats to managed and endangered cetaceans. Along the U.S. west coast, cetaceans are at risk of fishery interactions, entanglement, ship strike (Douglas et al., 2008; Carretta et al., 2014a), and anthropogenic sound sources such as seismic surveys, military sonar, and other vessel noise (Emmons et al., 2019).

Many cetacean species inhabit the outer coast of Washington State. These species are managed under the U.S. Marine Mammal Protection Act and include several stocks listed under the U.S. Endangered Species Act (Carretta et al., 2014b). The abundance and population density of cetaceans in the California Current off the U.S. Pacific Coast, including the Washington coast, has been estimated from summer and fall ship and aerial surveys (Barlow and Forney, 2007; Barlow, 2010; Chandler and Calambokidis[1]). However, species distribution in this area likely changes between seasons, since many cetacean species undertake long-distance annual migrations (Calambokidis et al., 2001). Forney and Barlow (1998) found that half of the abundance estimates for species surveyed off the California coast exhibited significant differences between the winter and summer surveys indicating that species' distribution in the California current changes seasonally. Determining cetacean seasonal distribution patterns is difficult and cost prohibitive due to protracted periods of inclement weather, remote access, and short daylight hours.

Previous attempts to better describe the year-round occurrence of cetaceans along the Washington coast have been limited temporally and spatially. Aerial surveys were conducted in the late 1980's and again in the 1990's (Shelden et al., 2000; Green et al.[2]). More recently non-systematic ship surveys have been conducted to locate endangered southern resident killer whales, *Orcinus orca*, in winter and spring months along the Washington and Oregon coasts (Hanson et al., 2010). Acoustic monitoring and associated small boat surveys have been employed to monitor marine mammal occurrence in the U.S. Navy Northwest Training Range Complex (Oleson and Hildebrand, 2012; Trickey et al., 2015), but these have been limited in space to two sites on the central

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doi: https://doi.org/10.7755/MFR.82.3-4.2

[1]Chandler, T., and J. Calambokidis. 2003. 2002 aerial surveys for harbor porpoise and other marine mammals off Oregon, Washington and British Columbia. Unpubl. rep. on file at Marine Mammal Laboratory, Alaska Fish. Sci. Cent., NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

[2]Green, G. A., J. J. Brueggeman, R. A. Grotefendt, C. E. Bowlby, M. L. Bonnell, and K. C. Balcomb. 1992. Cetacean distribution and abundance off Oregon and Washington 1989-1990. *In* J. J. Brueggerman (Editor), OR and WA marine mammal and seabird surveys. Ebasco Environ. Rep., Bellevue, WA (unpubl.), p. 1–100.

ABSTRACT—Seasonal occurrence of cetaceans along the Pacific Coast of Washington has been difficult to characterize because decreased daylight and inclement weather conditions result in a lack of consistent survey effort. Therefore, passive acoustic recorders were deployed at four sites along the Washington coast from 2008 to 2013 to record and detect sound-producing cetaceans. The most frequently detected cetaceans were gray whales, Eschrictius robustus; humpback whales, Megaptera novaengliae; *sperm whales,* Physeter macrocephalus; *and killer whales,* Orcinus orca. *Unlike the results from previous surveys, year-round acoustic monitoring indicates that migratory species such as gray, humpback, and sperm whales use parts of the Washington coast throughout the year. This information is essential for estimating the potential for human interactions such as entanglement or ship strikes with these species.*

Seasonal occurrence of the four species was variable between the four sites, even among those sites that were closest in proximity. These results indicate that caution should be used when extrapolating the results from a single site to a larger scale. Combining multiple sites into a loose network of recorders allowed us to characterize the spatial and seasonal occurrence of these cetaceans on the Washington coast during times of the year when aerial and ship surveys are not feasible. Additionally, we provide a baseline for monitoring yearly shifts in occurrence due to changing population demographics, oceanographic conditions, or anthropogenic inputs.

Table 1.—Recording effort for each location.

Location	Dates of recording	Depth (meters)	Sampling rate (kHz)	Seconds on/off	Total recording time (days)
Cape Flattery offshore	Oct 2008–Mar 2009	174	25	30/420	154
	Sep 2010–Jul 2011	169	25	30/600	334
	Oct 2011–Aug 2012	170	25	30/600	336
	Sep 2012–Sep 2013	168	25	30/600	371
Total					1,195
Cape Flattery inshore	Oct 2008–Feb 2009	115	25	30/420	145
	Sep 2010–Apr 2011	120	25	30/600	216
	Oct 2011–Mar 2012	115	25	30/600	187
	Aug 2012–Nov 2012	115	25	30/600	99
Total					647
Westport	Oct 2008–Feb 2009	63	25	30/420	145
	Nov 2010–Aug 2011	64	25	30/600	308
	Oct 2011–Aug 2012	64	25	30/600	328
	Oct 2012–Jun 2013	64	25	30/600	222
Total					1,003
Columbia River	Mar 2008–Jul 2008	80	25	30/300	71
	Dec 2008–Apr 2009	80	25	30/420	150
	Oct 2010–Sep 2011	111	25	30/600	336
	Oct 2011–Nov 2011	115	25	30/600	53
Total					610

Figure 1.—Deployment locations of Ecological Acoustic Recorders (EAR's) on the Washington coast.

Washington coast. It is difficult to determine how representative these are of coastwide and year-round cetacean occurrence.

As a part of a larger monitoring effort to examine resident killer whale movements from central California to the northwest tip of Washington State (Hanson et al., 2013), autonomous passive acoustic recorders were deployed at four sites along the Washington coast (Fig. 1). While the primary focus was to detect endangered southern resident killer whales during the winter and spring months, these recorders provided near year-round monitoring of sound-producing cetaceans. Here we describe the seasonal occurrence of the most frequently detected cetacean species along the Washington coast determined through passive acoustic monitoring: gray whales, *Eschrictius robustus*; humpback whales, *Megaptera novaengliae*; sperm whales, *Physeter macrocephalus*; and killer whales, *Orcinus orca*. This will provide the data necessary for determining how representative the previous studies that were limited spatially and seasonally are of coast-wide occurrence patterns.

Methods

Study Area

Ecological acoustic recorders (EAR's) (Lammers et al., 2008) were deployed at four sites spanning the continental shelf along the Washington coast from April 2008 to August 2013 (Fig. 1, 2; Table 1). Each recorder was part of a subsurface mooring that positioned the recorder approximately mid-water column (Table 1). Acoustic recorder locations were selected based on various factors which included previous killer whale sightings, sites where enhanced productivity would likely be concentrated due to bathymetric features, i.e., canyons heads (Denman and Powell, 1984; Mackas et al., 1997; Allen et al., 2001), accessibility for mooring deployment and recovery, and to reduce the likelihood of interactions with local fisheries (Hanson et al., 2013).

Data Collection

Each EAR is composed of four principal components: 1) the environmental interface module (hydrophone and water/pressure proof case), 2) the signal-conditioning module including the analog-to-digital device, 3) the central processing and storage unit, and 4)

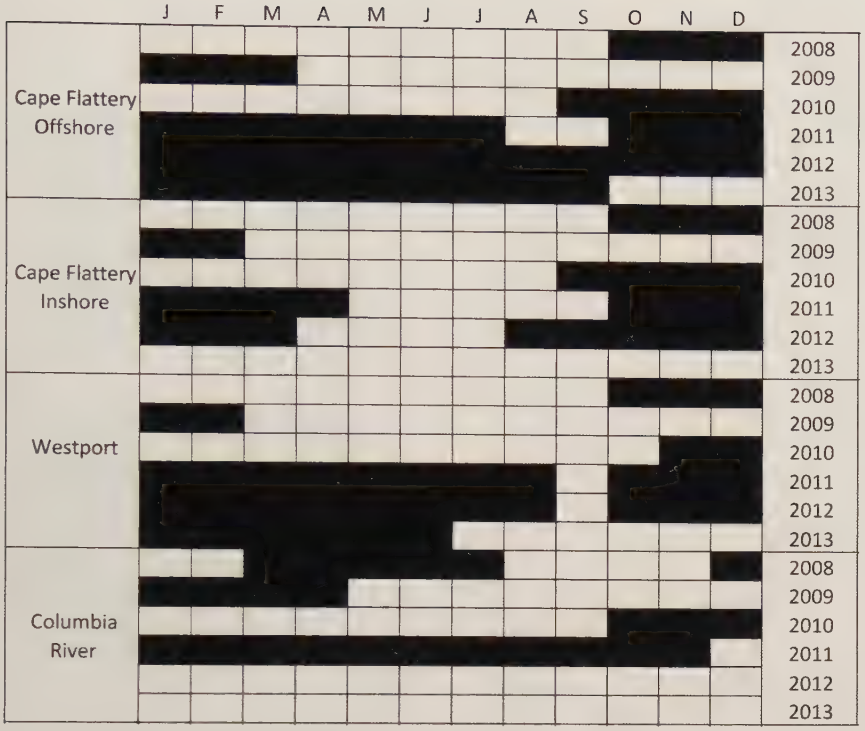


Figure 2.—Annual recorder effort by location.

the power supply. The system utilizes a hydrophone with a response sensitivity of -193.5 dB that is flat from 1–28 kHz (+/- 1.5 dB). Additional details on the specifications of the EAR are provided in Lammers et al. (2008).

In this study, EAR's were programmed to record on a 5–10% duty cycle depending on the year of deployment: 10% in 2008, 7% in 2009, and 5% for all subsequent years (Table 1). This resulted in 30 sec of continuous recording every 300 to 600 sec. Previous studies have shown that a reduced duty cycle may result in an underestimation of the time that species like killer whales, who vocalize in bouts, are acoustically present in the data set (Riera et al., 2013). Thomisch et al. (2015) found that a duty cycle which results in many short listening periods is preferred since it results in many daily samples, accounts for variability in vocal behavior, and is best suited for assessing acoustic presence.

To account for the differences in duty cycle between years, we used daily vocal occurrence as our unit of measure as in Hanson et al. (2013), in which the results indicated that the decreased duty cycle did not negatively affect the monthly detection rate of resident killer whales. The combination of a longer duty cycle and larger battery packs allowed for a year-long service life, except in cases of delays in deployment schedules, mooring failures, instrument service life limitations, or fishing gear interactions (Table 1).

The sampling rate used on all deployments was 25 kHz which provided 12.5 kHz of bandwidth. This was chosen as a compromise between the need to preserve hard-drive space and battery life while also providing enough information from individual recordings to identify killer whales (Hanson et al., 2013). The restricted bandwidth, calls from allospecifics, and increased seasonal ambient noise below 500 Hz limited which species we were reliably able to detect and identify. Therefore, odontocete sounds above 12.5 kHz and mysticete sounds below 500Hz were not included in this analysis.

For each deployment, all 30-sec recordings were sorted by day (the number of files per day was determined by the duty cycle) and then concatenated and converted into .wav files using a custom script in MATLAB[3]. The resulting files were reviewed visually and aurally in Raven Pro[4], and the sound sources present in the frequency range monitored were classified manually by comparing them to previously published descriptions of species-specific call and click types (Table 2). Those .wav files containing killer whale sounds were further reviewed, and discrete calls were compared to a catalog of pod and community specific dialects to determine the killer whale ecotype, community, and pod, if possible (Ford, 1987).

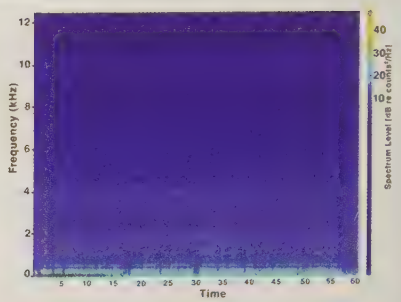
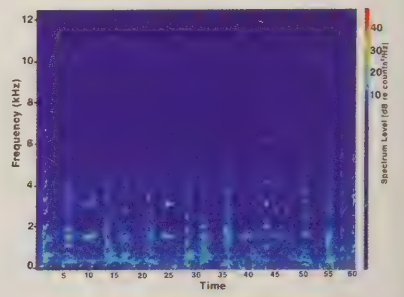
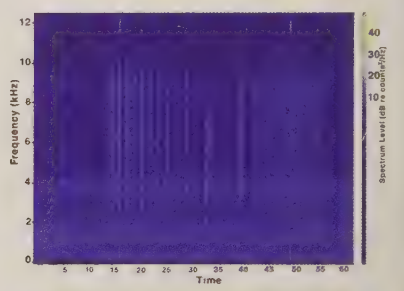
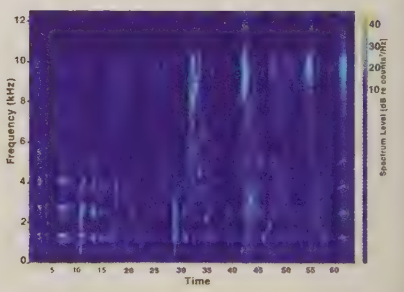
For each species monitored, we determined the daily vocal presence, which indicates that one or more individual was in the detection range of the recorder and produced a call. Occurrence was summarized on a 3-mo seasonal scale (fall: September–November, winter: December–February, spring: March–May, and summer: June–August) to account for gaps in monitoring due to equipment failure, fisheries interactions, and instrument deployment schedules while capturing migration patterns and changes in environmental conditions. Seasonal vocal presence for the study period was determined for each season by calculating the percentage of daily vocal presence normalized by the total number of days monitored in that season.

The observed and expected occurrence under a null model was summarized seasonally for each location using methods described in Hanson et al. (2013). To account for unequal sam-

[3]MathWorks. 2014. MATLAB release 2014b. The Mathworks, Inc. Natick, Mass. (http://www.mathworks.com/products/matlab/). Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[4]Bioacoustics Research Program. 2011. Raven Pro: Interactive Sound Analysis Software (Version 1.4). The Cornell Lab of Ornithology, Ithaca, N.Y. (http://www.birds.cornell.edu/raven).

Table 2.—Description of sounds used to identify species. Each spectrogram is 60 sec long and displays the full bandwidth, 12.5 kHz, monitored.

Species	Sound type	Description	References	Exemplars
Gray whale	M1 call, M3 call	M1: series of knocks; dominant sound type in breeding lagoons; comprises about half of the repertoire during migration M3: simply structured low frequency sound; only makes up 7% of repertoire in the breeding lagoons but increases to over 50% during migration	Dahlheim, 1987; Crane and Lashkari, 1996	
Humpback whale	Social sounds (non-song), song	Social sounds: produced by males and females; "grunts," "wops," and "moans"; associated with feeding grounds, but also heard during migration and infrequently on breeding grounds Song: produced by males; associated with breeding grounds; complex and structured series of vocalizations	Au et al., 2006; Stimpert et al., 2011	
Sperm whale	Usual clicks, slow clicks (rare)	Usual clicks: broadband clicks with an interclick interval of 0.5–1 second; long-range echolocation Slow clicks: broadband clicks with an interclick of greater than 1 second	Jaquet et al., 2001; Weilgart and Whitehead, 1988	
Killer whale	Pulsed calls, clicks, whistles	Pulsed calls: stereotyped broadband calls; ecotype, community, and pod specific; group cohesion Clicks: short duration, broadband; echolocation Whistles: nonpulsed or continuous tones with average bandwidth of 4.5 kHz; close-range motivational sounds	Ford, 1989; Barrett-Lennard et al., 1996; Thomsen et al., 2001; Foote and Nystuen, 2008	

pling between seasons, the expected occurrence was estimated by multiplying the total number of days with detections in a given season by the proportional contribution of days monitored in that season (total number of days for a season divided by the total number of days monitored during that season in the study). For each species, differences in seasonal vocal presence and year-round occurrence at each location were determined using analysis of variance (ANOVA). Post hoc Tukey tests were also run to further investigate the differences between each pair of seasons and locations.

Results

Between 2008 and 2013, the number of days monitored at each site was variable (Fig. 2, Table 1). Since the primary interest in killer whale monitoring was to fill the data gap of winter and spring movements, de-

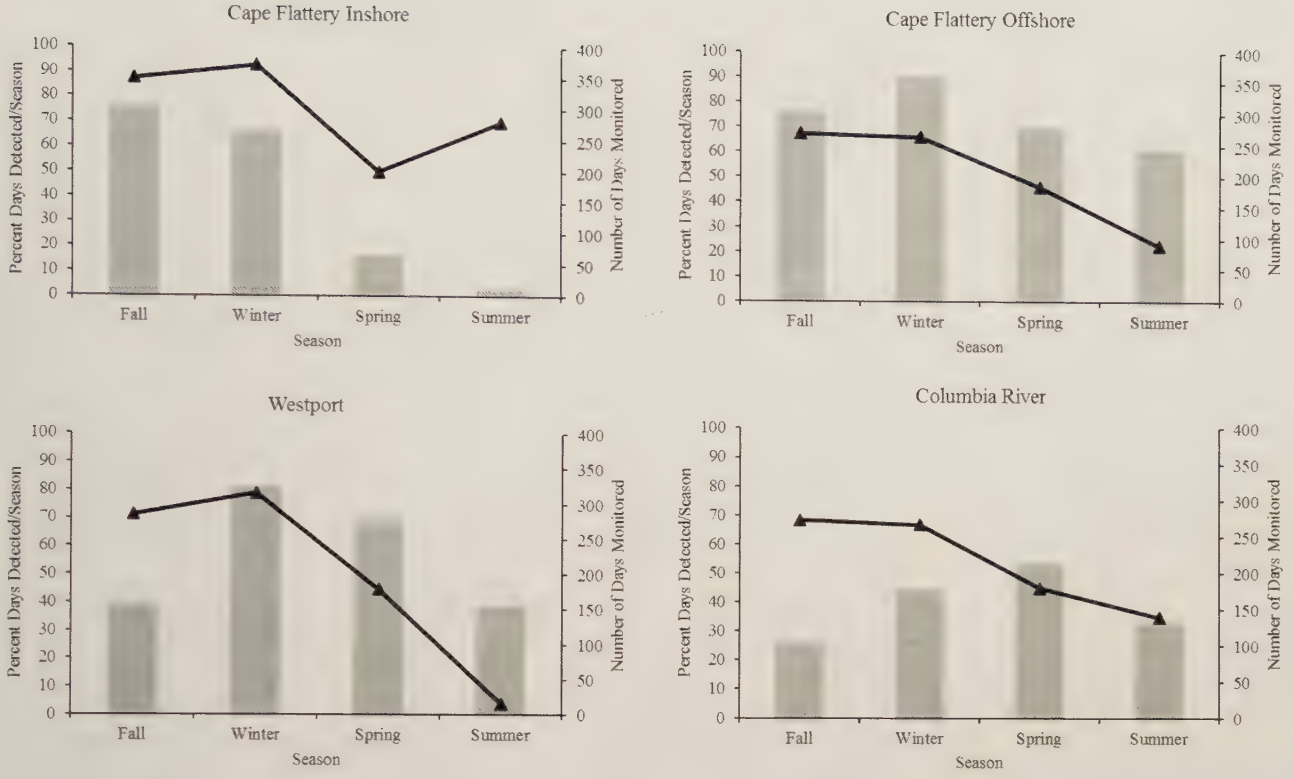


Figure 3.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with gray whale detections at each location in a season.

ployments and recoveries of moorings were scheduled during the summer and fall months. This, combined with fishing gear interactions and instrument life limitations, restricted the summer monitoring effort. The combination of a longer recording duty cycle and larger battery packs allowed for a year-long service life, which led to increased effort beginning in 2011.

The most common cetacean species detected during the monitoring period are, in decreasing order of occurrence: gray whales, humpback whales, killer whales, and sperm whales (60%, 46%, 19%, and 13% of all days monitored at all sites, respectively). Additionally, there were a number of sounds that have not been identified to species. These include unidentified delphinid clicks and whistles, pinniped calls, signals occurring below 500 Hz, and some sounds that did not have an adequate signal to noise ratio to be identified. Details of species-specific occurrence are described below.

Gray Whales

Detections of gray whales were most common at all four sites during the fall and winter seasons, declined during the spring season, and were the lowest during the summer (Fig. 3). This trend was the weakest at the Columbia River site. At both of the nearshore sites, Cape Flattery inshore and Westport, gray whales were detected on more days than expected during the fall and winter (Fig. 3). At all sites, occurrence during the spring matched the expected occurrence, while summer occurrence was higher than expected at the Cape Flattery offshore and Columbia River sites (Fig. 4). A one-way ANOVA showed a significant difference in the seasonal occurrence of gray whales at all sites combined ($F(3,44)$=4.24, P=0.01), with higher occurrence in fall than in spring and summer (Tukey's test, $P< 0.05$). There was no significant difference in the year-round occurrence among the sites ($F(3,6)$=2.55, P=0.068).

Humpback Whales

Humpback whales were detected at each site in all seasons monitored with their occurrence peaking at all sites during fall months (September–November) and the lowest levels of occurrence during winter and spring months (Fig. 5). Occurrence in all seasons was lower than expected at the two southern sites, Westport and the Columbia River (Fig. 4). At the Cape Flattery inshore site, occurrence was higher than expected during the fall and winter (Fig. 3). The Cape Flattery offshore site had the highest occurrence of humpbacks whales throughout the year, and occurrence was higher than expected in all seasons (Fig. 4). A one-way ANOVA showed a significant difference in the seasonal occurrence of

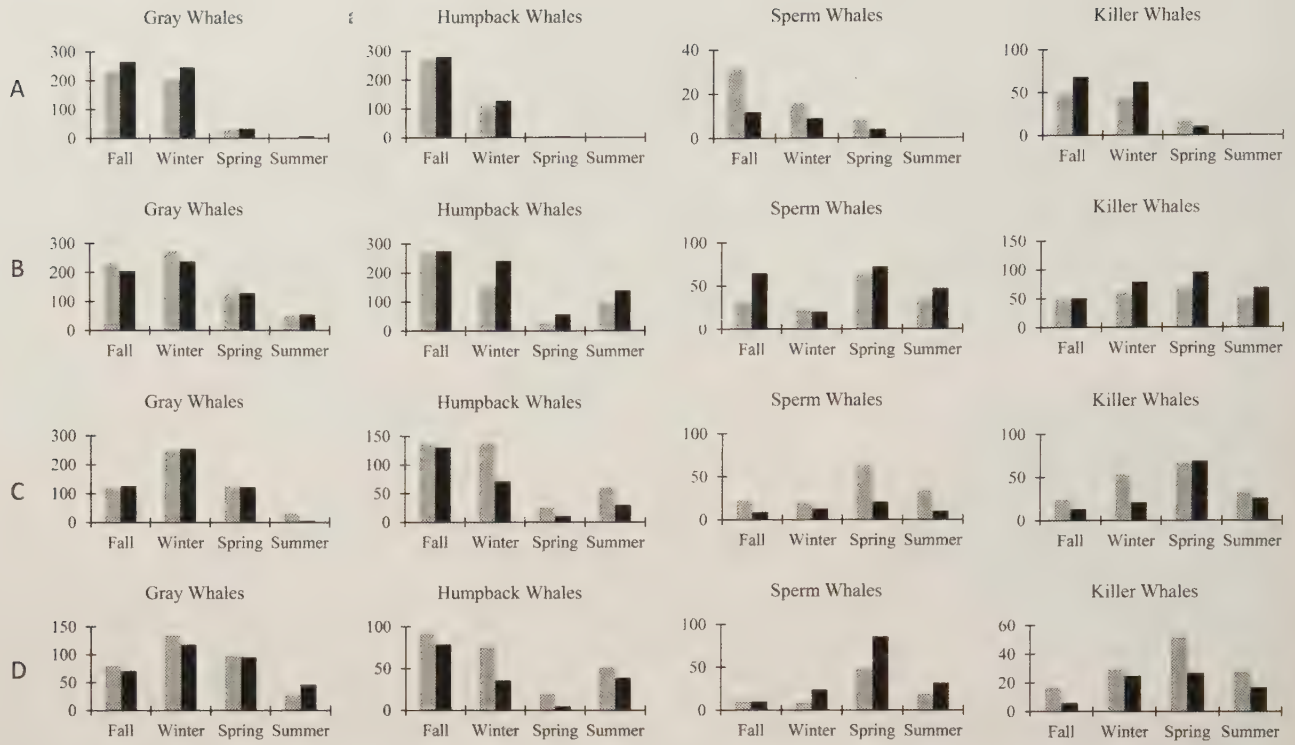


Figure 4.—Seasonal observed occurrence (black bars) versus expected occurrence (gray bars) for each species at (a) Cape Flattery Inshore, (b) Cape Flattery Offshore, (c) Westport, and (d) Columbia River.

humpback whales at all sites combined ($F(3,43)$=2.82, P=0.00), with higher occurrence in fall than in other seasons (Tukey's test, $P< 0.05$). There was no significant difference in the year-round occurrence among the sites ($F(3,43)$=2.39, P=0.08). Singing behavior was detected at all sites during the fall and extended into December and January in some cases, while social sounds were detected throughout the year at all sites.

Sperm Whales

Sperm whales were detected at all sites in every season, but their occurrence varied between sites and seasons (Fig. 6). The two near-shore sites had low levels of occurrence (<5% of days monitored) in each season with minor peaks in the spring. The occurrence at these two sites was less than expected in all seasons (Fig. 4). Sperm whales were more frequently detected at the Cape Flattery Offshore and Columbia River sites. Occurrence at these sites was higher than expected in all seasons except during the winter at Cape Flattery offshore (Fig. 4). The spring peak in detections was greatest at the Columbia River site with sperm whales detected on 43.5% of days as opposed to 26.1% at the Cape Flattery offshore site. A one-way ANOVA indicated there was no significant difference in seasonal occurrence of sperm whales at all sites combined ($F(3,43)$=0.849, P=0.5). There was a significant difference in the year-round occurrence of sperm whales among the sites ($F(3,43)$=8.25, P=0.00), with significant differences between the near-shore sites and the Cape Flattery offshore and Columbia River sites (Tukey's test, $P< 0.05$).

Killer Whales

Killer whales were detected at each site in every month monitored (Fig. 7). In every season, killer whale detections were more frequent at the two northern sites, Cape Flattery inshore and offshore, and occurrence was greater than expected in all seasons at the offshore site and during the fall and winter at the inshore site (Fig. 4). At the two southern sites, Westport and the Columbia River, occurrence was less than expected in all seasons except for spring at the Westport site (Fig. 4). At both southern sites, fish-eating "resident" killer whales were most frequently detected between the months of January and June. All these resident detections were of the southern resident community except for one in March 2012. At the northern sites both northern and southern resident killer whales were detected frequently.

During the period that southern resident occurrence is highest at the southern sites (January–April) northern residents were detected at the northern sites more frequently. Additionally, there was an increase in north-

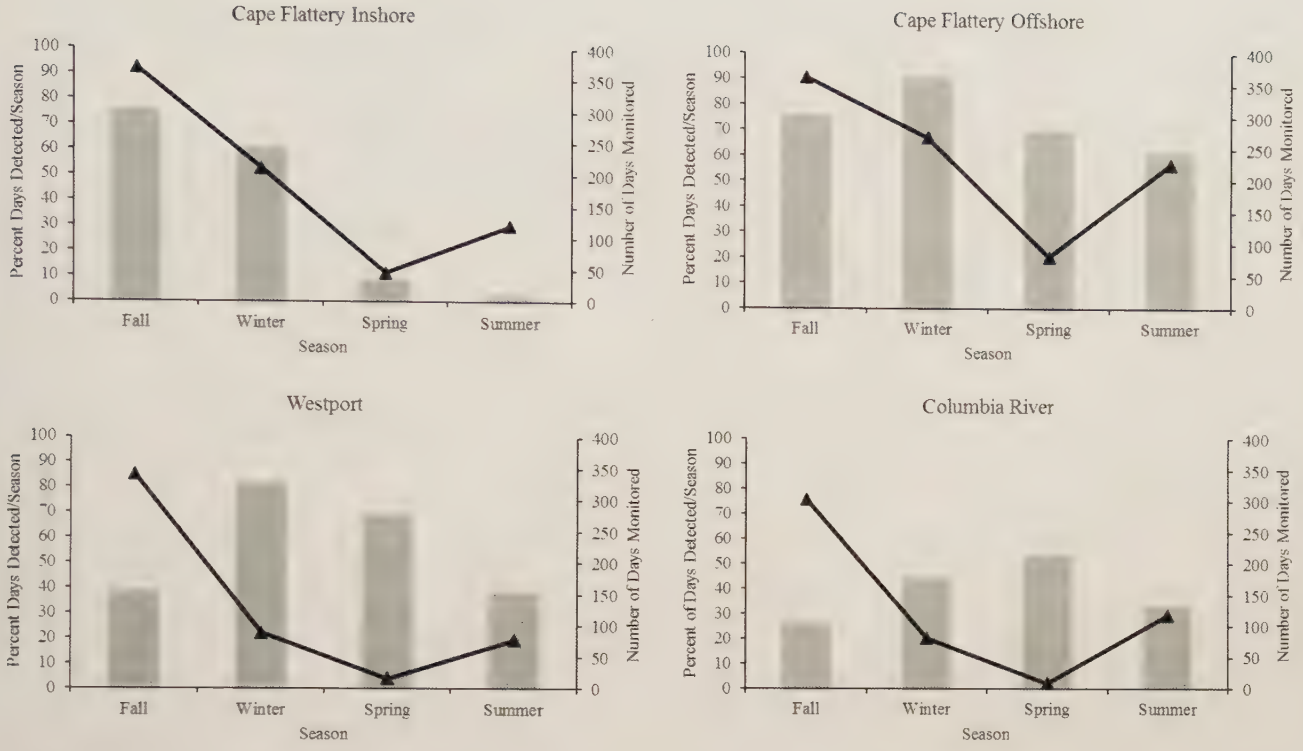


Figure 5.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with humpback whale detections at each location in a season.

ern resident detections in the late summer/fall. Mammal eating "transient" killer whales were detected throughout the year at all sites.

There was not sufficient sample size to complete statistical analyses for each killer whale ecotype or group separately. A one-way ANOVA showed no significant difference in the seasonal occurrence of killer whales at all sites combined ($F(3,44)$=2.17, P=0.11). There was a significant difference in the year-round occurrence of killer whales among the sites ($F(3,44)$=7.46, P=0.00), with a significant difference between the Cape Flattery offshore site and the two southern sites (Tukey's test, $P< 0.05$).

Discussion

Utilizing a loose network of passive acoustic recorders, we have been able to characterize the spatial and seasonal occurrence of several cetacean species on the Washington coast during times of the year in which aerial and ship surveys are not practical. These results can also be combined with previous visual and acoustic survey results that have been limited temporally and spatially to describe year-round occurrence of these species. Additionally, we provide a baseline to monitor yearly shifts in occurrence due to changing population demographics, oceanographic conditions, or anthropogenic inputs.

Gray whale detections at all sites monitored corresponded with the timing of migration south to the breeding grounds off Baja, Calif., usually starting in November (Swartz et al., 2006) and back north to feeding grounds in the Bering and Chukchi Seas beginning in mid-February (Poole, 1984). The winter peak in detections was also found in previous acoustic monitoring at nearby sites along the southern Washington coast (Sirovic et al., 2011). The migration signal was weakest at the two more offshore sites and strongest at the two inshore sites, which may be due to the tendency of this species to migrate close to shore (Shelden and Laake, 2002). The year round occurrence of gray whale detections at these sites, which were chosen due to their proximity to areas of high primary productivity, may be due to gray whales that do not migrate north and spend the summer feeding off the Oregon and Washington coasts (Calambokidis et al., 2002).

Humpback whale detections also corresponded to known migratory patterns (Calambokidis et al., 2001) with decreased detections in the winter and spring, the period that humpback whales are encountered on their breeding grounds in Hawaii and Mexico. While detections decreased during the winter and spring, the detections during these seasons indicate that humpback whales can be found along the Washington coast throughout the year.

These results are in agreement with

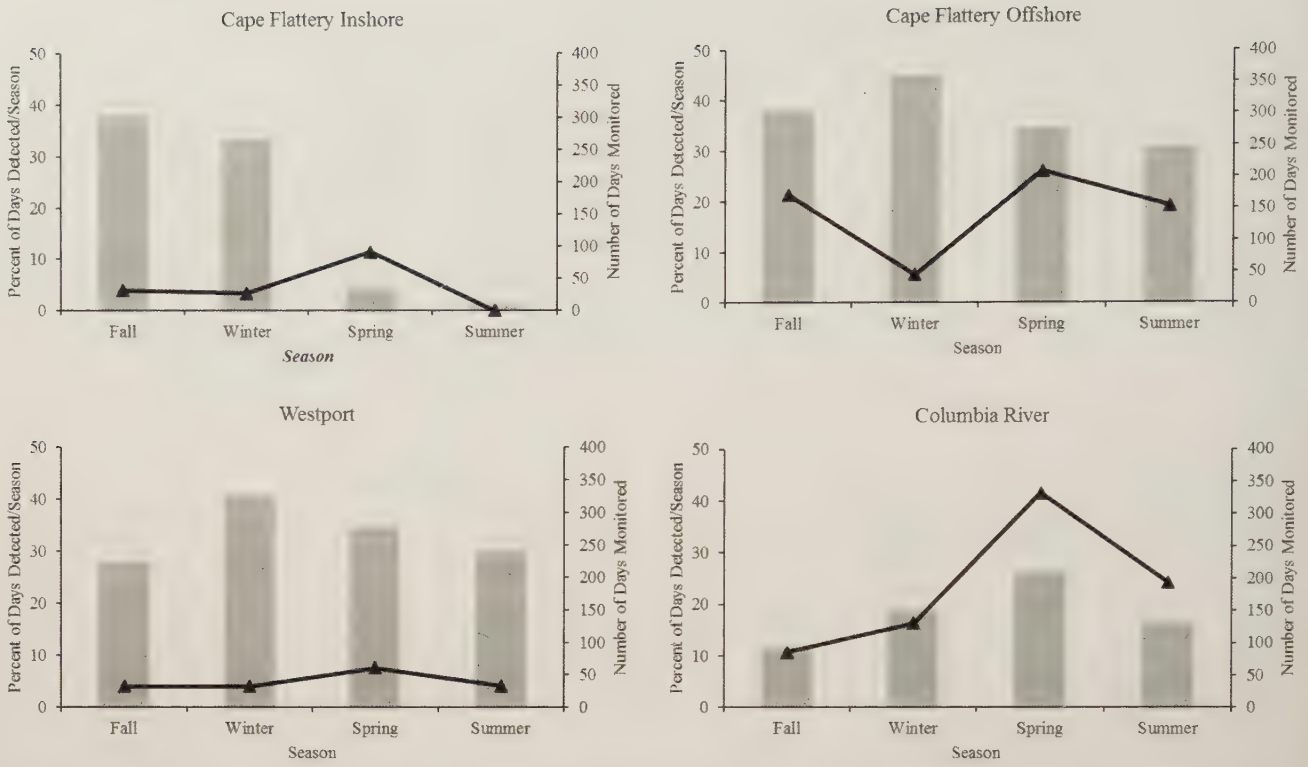


Figure 6.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with sperm whale detections at each location in a season.

acoustic monitoring at two sites along the southern Washington coast beginning in 2004 (Sirovic et al., 2011; Sirovic et al., 2012; Trickey et al., 2015), but earlier winter systematic visual surveys did not observe humpbacks during winter months (Shelden et al., 2000; Green et al.[2]). This may be an emerging pattern of occurrence. The northeast Pacific humpback whale population has grown to pre-whaling estimates of abundance (Barlow et al., 2011) and has seasonally expanded its range to include areas previously not used (Seely et al., 2017). The higher occurrence at the Cape Flattery offshore site is probably due to its proximity to an important feeding area off the northern Washington coast (Calambokidis et al., 2004).

Sperm whales had previously been reported off the Washington Coast in all seasons except winter (Sirovic et al., 2011; Green et al.[2]), but in this study they were detected at each site during these months at low levels. During previous systematic surveys, sperm whales were not observed in the shelf waters off the Washington coast (Barlow and Forney, 2007; Green et al.[2]) where all of our recorders were located. The greater number of detections at the Columbia River and Cape Flattery offshore sites may be due to proximity of these moorings to the Astoria and Nitinat canyons, respectively, as sperm whale density has been shown to be correlated with areas of steep underwater topography (Jaquet and Whitehead, 1996). The smaller numbers of detections at the Cape Flattery inshore and Westport sites may be indicative of whales transiting through the near-shore waters of Washington State, which has been observed in previous satellite tagging studies (Straley et al., 2014).

Moore and Barlow (2014) found that the number of sperm whales in the California Current has increased, and estimate a two-fold increase from 1991 to 2008. These are most likely adult males traveling alone or in pairs. Sperm whale distribution is of particular management interest due to their endangered status and interactions with fisheries (Hucke-Gaete et al., 2004; Sigler et al., 2008), and visual surveys for this species can be challenging due to the limited amount of time they spend at the surface. While diving, sperm whales regularly make relatively loud clicks making them amenable to acoustic detection and monitoring to assess seasonal occurrence and distribution (Barlow and Taylor, 2005).

Killer whale occurrence at the two southern sites was highest from January to June. This is primarily due to the increased presence of southern resident killer whales, which is likely driven by the timing of Chinook salmon, *Oncorhynchus tshawytscha*, returning to the Columbia River (Han-

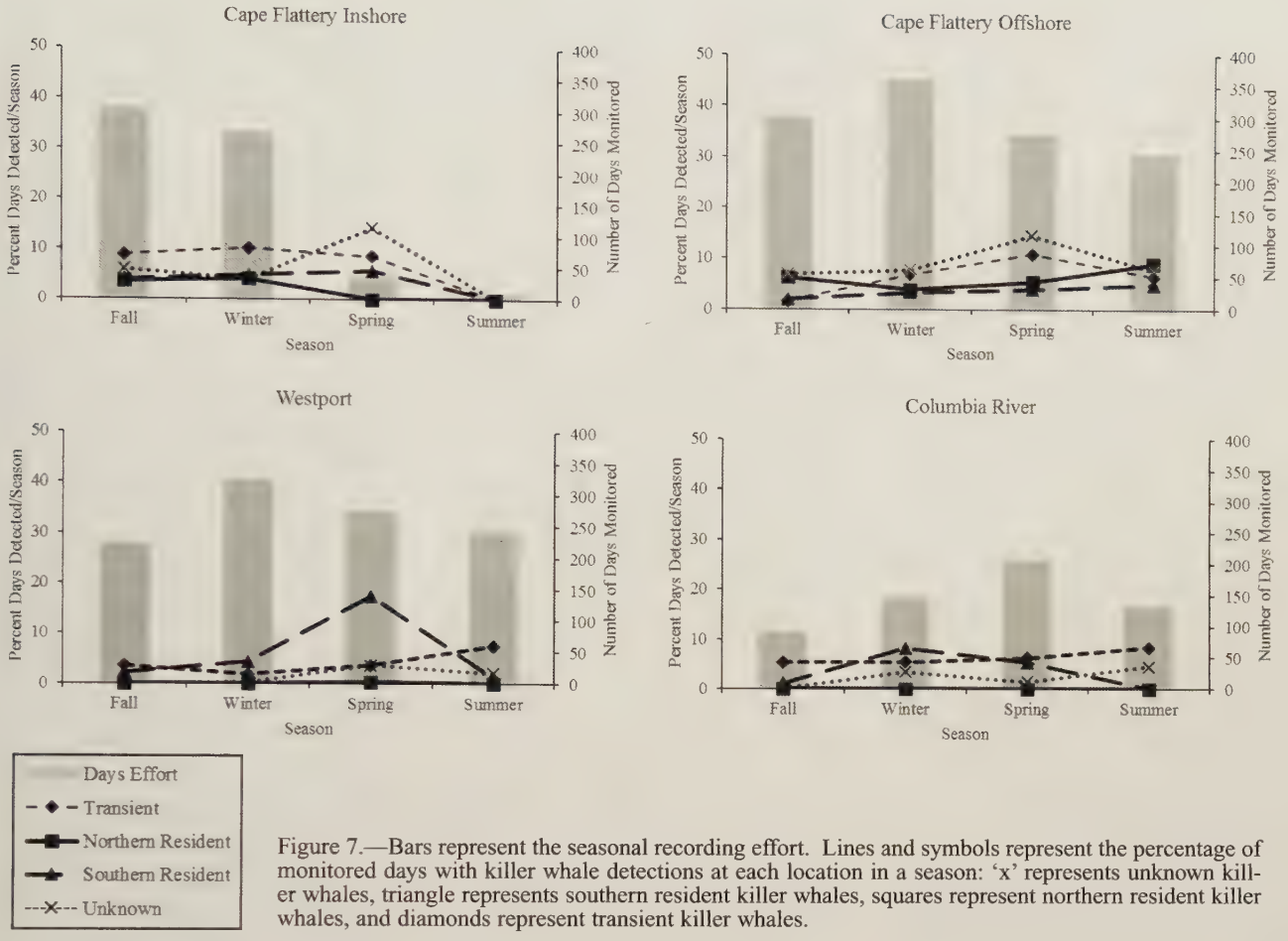


Figure 7.—Bars represent the seasonal recording effort. Lines and symbols represent the percentage of monitored days with killer whale detections at each location in a season: 'x' represents unknown killer whales, triangle represents southern resident killer whales, squares represent northern resident killer whales, and diamonds represent transient killer whales.

son et al., 2013; Rice et al., 2017). By June, transient killer whale detections become more common, even though they are detected at low levels at both sites throughout the year. Rice et al. (2017) also found increased transient killer whale detections in the spring and early summer at two sites along the Washington coast from 2004 to 2013. This timing corresponds to harbor seal, *Phoca vitulina*, pupping season on the Washington coast (Seekins[5]) and the usual return of resident killer whales to inland waters (Hauser et al., 2007). Both resident and transient killer whales were detected more often at the two northern sites which may be a result of the moorings proximity to important foraging areas and the Straits of Juan de Fuca (Baird and Dill, 1995; Ford et al., 2010; Hanson et al., 2010) and corresponds to previous monitoring in the area (Riera et al., 2011; Riera, 2012).

Passive acoustic monitoring has been shown to be an effective tool for examining cetacean occurrence and seasonality in areas of conservation or mitigation interest that are relatively small such as military ranges, renewable energy installations, and marine protected areas (Hazen et al., 2011; Oleson and Hildebrand, 2012; Lammers et al., 2013). It is unclear if it is appropriate to use the results from a single site to infer movements and seasonality on a larger scale, because little is known about variability in distribution of many species across seasons and locations. The results of this study indicate that caution should be used when extrapolating the results of site-specific monitoring to a larger scale. The seasonal occurrence of the four species monitored was variable between the four sites, even amongst those sites that were closest in proximity. For example, gray whales were detected throughout the summer months at the Columbia River site, while they were absent during these months at the other southern site, Westport. And while the acoustic environment may differ among the sites, there were no consistent patterns observed that indicated reduced detection ranges at any given site.

Year-round acoustic monitoring also indicates that species that under-

[5]Seekins, B. 2009. Harbor seal pupping timeframes in Washington State (avail. online at http://www.westcoast.fisheries.noaa.gov/publications/gis_maps/maps/marine_mammals/seal-pups-timing.pdf (accessed 8 Apr. 2013)).

take long-distance annual migrations, such as gray, humpback, and sperm whales, use parts of the Washington coast for the entire year. This information is essential for estimating the potential for human interactions, such as entanglement or ship strike, to these species and for monitoring changes in migration timing and seasonal occurrence over time.

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Anthropogenic Scarring in Long-term Photo-identification Records of Cook Inlet Beluga Whales, *Delphinapterus leucas*

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Introduction

Vessel strikes, entanglement, poaching, intentional harassment, and invasive research are among many possible threats to Alaska's endangered Cook Inlet beluga whales (CIBW), *Delphinapterus leucas,* according to the Recovery Plan (NMFS[1]) for this population. Geographically and genetically isolated from other beluga populations around Alaska, the CIBW population is listed as an "endangered" Distinct Population Segment (DPS) by NOAA's National Marine Fisheries Service (NMFS), the Federal agency responsible for its protection.

The designation under the U.S. Endangered Species Act (ESA) occurred in October 2008 (NOAA, 2008) and was preceded by a steep decline in the CIBW population during the 1990's and a designation as "depleted" in 2000 under the Marine Mammal Protection Act (NOAA, 2000). An unsustainable level of hunting by Native Alaskans (Mahoney and Shelden, 2000) was thought to be the primary cause of the initial population decline. Cooperative agreements between NMFS and subsistence users suspended CIBW hunting after 2006 (NOAA, 2008). If subsistence hunting was the only factor limiting population growth, the population was expected to have recovered in the following decade. However, a survey by NMFS conducted in June 2018 found the population has continued to decline at a rate of about 2% per year since the ESA listing in 2008 (Wade et al.[2]).

The reasons for this decline remain unknown. The CIBW Recovery Plan lists ten likely threats to CIBW recovery, including injury and death from anthropogenic activities (referred to collectively in the Plan as "unauthorized take," although this category also includes NMFS authorized take for research). Unauthorized take is categorized as a threat of medium concern in the CIBW Recovery Plan, with the level of concern affected, in part, by uncertainties about magnitude and trend.

Establishing a baseline estimate of the current magnitude of this threat is necessary for establishing and monitoring future trends. The shores of Cook Inlet are inhabited by most of Alaska's human population and in-

[1]NMFS. 2016. Recovery plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). NMFS Protected Resources Div., Alaska Region, Juneau, AK (https://repository.library.noaa.gov/view/noaa/15979).

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[2]Wade, P. R., C. Boyd, K. E. W. Shelden, and C. L. Sims. 2019. Chapter 2: Group size estimates and revised abundance estimates and trend for the Cook Inlet beluga population. *In* K. E. W. Shelden, and P. R. Wade (Editors). 2019. Aerial surveys, distribution, abundance, and trend of belugas (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2018. AFSC Proc. Rep. 2019-09, 93 p. (https://apps-afsc.fisheries.noaa.gov/documents/PR2019-09.pdf).

ABSTRACT—Vessel strikes, entanglement, poaching, intentional harassment, and invasive research are possible direct anthropogenic threats to the endangered Cook Inlet beluga whale, Delphinapterus leucas, *population (CIBW) according to the CIBW Recovery Plan. Establishing the prevalence of such threats is necessary for understanding impact and monitoring future trends. We examined records of individual belugas photographed during 2005–17, along with stranding records during this time, to determine prevalence of scars indicative of anthropogenic trauma, and classified these scars according to their likely sources (e.g., entanglements, vessel strikes, puncture wounds, and research). In this combined dataset, 37.7% of 106 individuals had scars classified as either confirmed or possible anthropogenic origin. In the photo-ID records, 15% of individuals had signs of confirmed or possible entanglement, 14% had signs of confirmed or possible vessel strikes, 5% had signs of possible puncture scars, and 24% had research scars. Out of 33 necropsied belugas, 6% had scars from satellite tagging, 6% had signs of entanglement, 3% had possible signs of a vessel strike, and 3% had possible signs of puncture scars. We also examined wound healing, reproduction, and survival of individuals with scars consistent with anthropogenic trauma. One important result from this work is that trauma from anthropogenic sources may take years to manifest. From our limited sample we cannot directly infer the population-level prevalence of anthropogenic trauma, but our assessment shows the source and prevalence in the sample; this is a preliminary step in understanding how anthropogenic trauma may be contributing to the population's continued decline.*

cludes Anchorage, the largest urban area in the state. Humans use Cook Inlet for fishing, hunting, shipping, timber harvest, mining, dredging, renewable energy, discharge of wastewater, military activities, oil and gas development, transportation, and residential and industrial development (Fig. 1). Belugas are not uniformly distributed throughout Cook Inlet, but are predominately found in nearshore waters of upper Cook Inlet, overlapping areas of high human activity (Shelden et al., 2015). With the exception of subsistence hunting of northern and western beluga stocks, the potential for injury and death from anthropogenic activities is likely higher for CIBW's than for other beluga populations found in more remote areas of Alaska and likely to increase with a growing human population around the inlet (NMFS[1]).

Longitudinal studies of individual belugas who have experienced anthropogenic injury may provide insight into the prevalence and consequences of these threats through time and how such injuries may affect the CIBW population. Image analysis from photo-identification (photo-ID) catalogs has been successfully used for health assessment and threat risk analysis of cetaceans, including endangered baleen whale stocks such as North Atlantic right whales, *Eubalaena glacialis* (Moore and van der Hoop, 2012; Rolland et al., 2016), Okhotsk Sea bowhead whales, *Balaena mysticetus* (Shpak and Stimmelmayr, 2017), Bering-Chukchi-Beaufort Sea bowhead whales (George et al., 1994; 2017), and western gray whales, *Eschrichtius robustus* (Bradford et al., 2009). It has also been used for the long-term monitoring of small cetaceans in an estuarine environment (Wells et al., 2008) and for evaluating the effects of research activities such as satellite tagging on individual cetaceans (Gendron et al., 2015).

The CIBW Photo-ID Project began developing a photo-ID catalog of individually identified belugas in 2005 to establish a long-term, noninvasive data set to monitor the CIBW population. With approximately 400 individuals

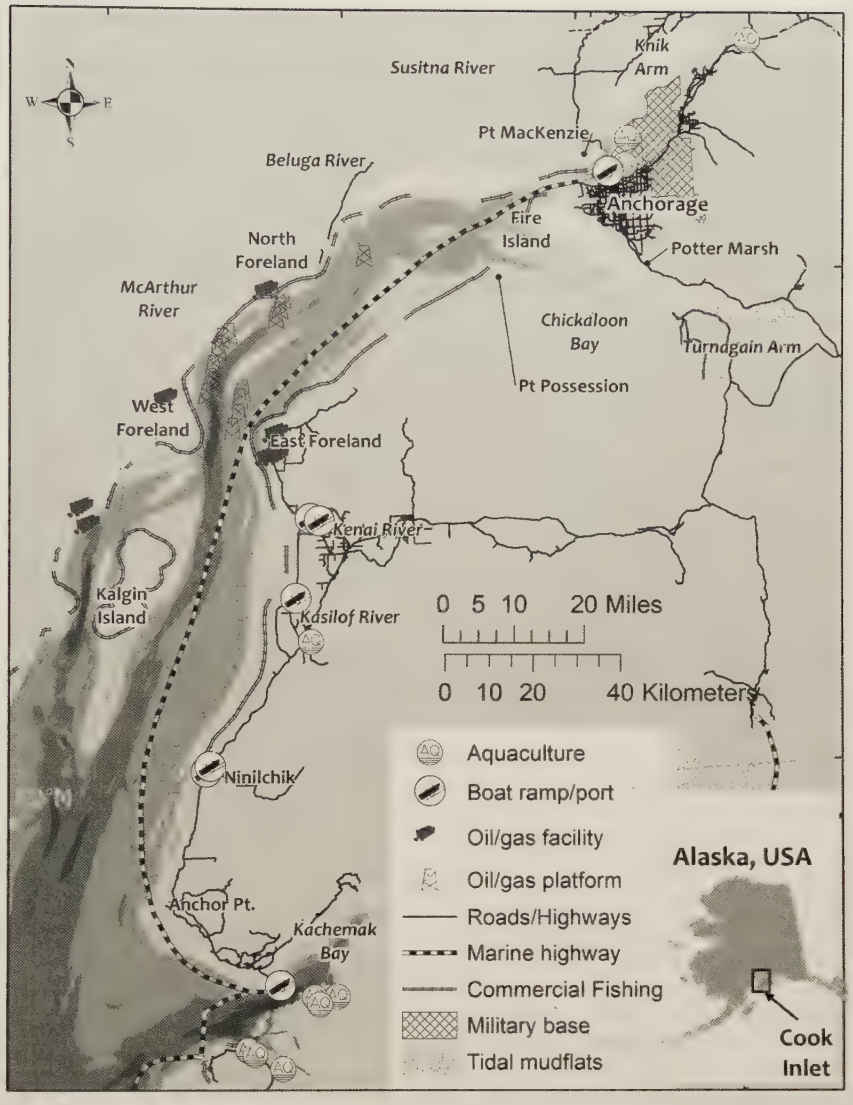


Figure 1.—Cook Inlet, Alaska.

in the catalog as of the end of 2017, it consists of most of the adult and subadult CIBW population over the last 13 years, as well as calves who were too young to be identified by their own marks. Marks used for identification are long-lasting and allow information on individual survival and reproduction to be collected over time. Photographs also allow for examination of scars resulting from anthropogenic injury on those parts of the body visible above water while the whale is alive, and on all visible areas of carcasses. Photographs of live whales following an injury provide information on wound healing and body condition, and long-term photographic sighting records of injured individuals can be assessed for survival and reproduction. We therefore examine both datasets, but present some results separately.

In this paper, we

1) review photographic records of belugas in the photo-ID catalog and stranding database to identify scars indicative of anthropogenic injury;
2) classify these scars according to their likely sources (entanglement, vessel strike, hunting/

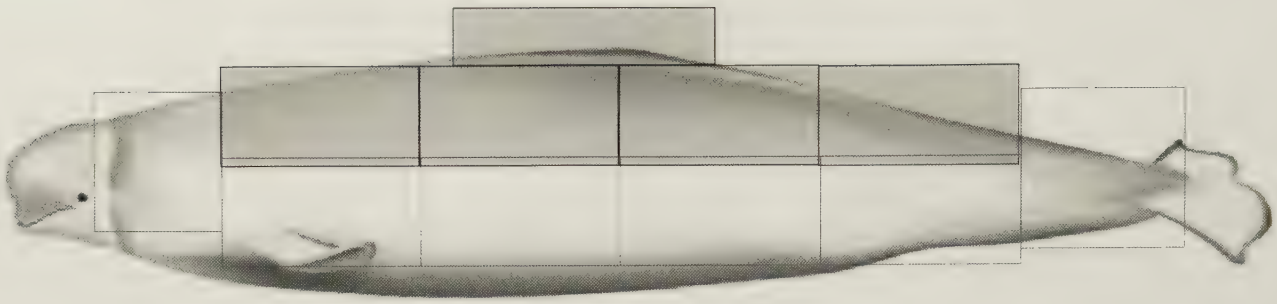


Figure 2.—Beluga body segments used for cataloging photographs for identification. The five shaded areas are the critical sections used in classifying anthropogenic scars. Beluga illustration courtesy of Uko Gorter.

poaching/harassment, and invasive research) and their location on the body;

3) estimate the prevalence of each anthropogenic scar type in the photo-ID catalog; and
4) examine the photographic sighting histories of belugas with anthropogenic scarring to document their subsequent healing, survival, and reproduction.

Methods

Photo-ID Data

The photo-ID catalog was created from photographs taken during 477 photo-ID surveys conducted over 13 consecutive field seasons (2005–17) in Cook Inlet, an estuary in southcentral Alaska (Fig. 1). At the time of this study, the summer CIBW range had contracted to the area north of East and West Foreland (Rugh et al., 2010; Shelden et al., 2015), hereafter referred to as the Upper Inlet. Most of the photo-ID survey effort was concentrated in the Upper Inlet, with some effort in and around the Kenai River (Fig. 1).

Surveys were conducted during the ice-free season (April–October), with most effort in August and September, and least effort in April. Surveys were conducted from small vessels (58%) and from shore (42%). Free-swimming beluga whales were photographed with digital SLR cameras with a telephoto image-stabilized zoom lens (100–400 mm) with auto-focus. We also reviewed and cataloged photographs of live belugas shared with us from the public and colleagues. These shared photos were taken with a variety of cameras, cell phones, and other digital devices, and were held to the same quality standards as those collected during photo-ID surveys.

Marks used to identify individuals consisted of pigmentation patterns, scars from disease or anthropogenic injury, and scars that likely came from other sources such as competition (among conspecifics, or interspecific from harbor seals, *Phoca vitulina*), social interactions among conspecifics, predation (sharks: *Carcharodon carcharias, Somniosus pacificus, Lamna ditropis*; killer whales, *Orcinus orca*; and possibly brown bears, *Ursus arctos*), natural debris in high currents, or scraping themselves against rocks, sea ice, or other hard substrates (LGL[3]).

Turbidity in Cook Inlet is high from glacial sediments and prevents visibility below the waterline in the Upper Inlet. As a beluga surfaces and submerges, different portions of its body are available to be photographed. Side-profile images were used to identify individuals and were divided into 11 sections along the right and left sides of the whales. The five body sections along the spine (Fig. 2) are those used for identification because the six sections containing the head, tail, and ventrum of the whale are not commonly captured in photographs.

A right- or left-side profile set was considered complete and included in the catalog, given a unique ID number, and considered an individual if it contained high-quality images of all five sections along the spine of the whale, beginning just behind the blowhole and extending to the base of the tail (i.e., shaded sections in Figure 2). An individual could also be accepted into the catalog if it was photographed in multiple years, even if it did not have high-quality images from all five body sections, but only after photo-analysts ensured that it could not be matched to existing individuals in the catalog. All matches in the existing catalog were reviewed and verified by at least two experienced photo-analysts. Further details of the photo-ID methods are presented in McGuire and Stephens.[4]

Because photographs taken from vessels or shore were lateral views of one side of a beluga's body, separate catalogs were created for the

[3]LGL Alaska Research Associates. 2009. Photo-identification of beluga whales in Upper Cook Inlet, Alaska: mark analysis, mark-resight estimates, and color analysis from photographs taken in 2008. Rep. prep. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 99 p. (avail. online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_7113cf2e054547009605bf8884568b1e.pdf).

[4]McGuire, T., and A. Stephens. 2017. Photo-identification of beluga whales in Cook Inlet, Alaska: Summary and synthesis of 2005–2015 data. Rep. prep for National Marine Fisheries Service, Alaska Region. LGL Alaska Res. Assoc., Inc., Anchorage, AK, 229 p. (avail. online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_4a6dbde631be4de685f764a73cf16908.pdf).

right-side images, the left-side images, and the dual-side images. Photo-ID studies of other cetaceans, such as bottlenose dolphins, *Tursiops truncatus*, often use images of the dorsal fin to identify individuals, and these individuals can be recognized by fin shape and marks along the trailing edge that are visible from either side. Belugas do not have a dorsal fin, and therefore could only be classified as dual-side individuals if 1) they met the criteria to be classified as individuals in both right- and left-side catalogs, and 2) if marks that spanned both sides of the body could be seen and used to link the two sides.

Aerial photography from drones was not feasible from 2005 to 2016 due to research permit restrictions from NMFS and flight restrictions from the Federal Aviation Administration. However, in 2017, NMFS began photographing CIBW's from drones and has made some of these images available to us, which has facilitated the matching of right and left sides and allowed for the addition of 23 dual-side linkages to our previous count of 55. The 2005–17 CIBW photo-ID catalog contains records for 423 individuals identified from photographs of their right sides, 431 individuals identified from their left sides, and 78 "dual" individuals (i.e., matched between both catalogs, and also contained within the left- and right-side catalogs).

Stranding Data

Between 2005 and 2017, 95 dead CIBW's were reported to NMFS and photographs were taken of 41 of these (McGuire et al., 2020b). Necropsies (conducted by the Alaska Marine Mammal Stranding Network under the authorization of NMFS) were performed on 33 of the 41 individuals that were photographed. Five of the necropsied whales were matched to individuals in the dual-side photo-ID catalog. Tissues and teeth were collected from some individuals (n = 34), either during necropsy or during brief examination without necropsy. For these individuals, ages were estimated from growth layers in the teeth, assuming one growth layer group (GLG) per year (Vos et al., 2019). A retrospective analysis of the reproductive status of dead females (n = 16) was conducted based on laboratory examination of their reproductive tract (Shelden et al., 2019a). The sex of necropsied individuals was confirmed using genetic methods. In brief, total DNA was extracted from tissue samples by established protocols (e.g., O'Corry-Crowe et al., 1997), and the genetic sex of each sample was determined by PCR-based methods (Fain and LeMay, 1995). In addition to collecting biological data and samples, examining veterinarians attempted to determine the cause of death (COD) during necropsy.

Classification of Anthropogenic Scarring

Categories of scars were developed by comparing scars and deformities seen on individuals in the CIBW photo-ID catalog and stranding photos to descriptive classifications and photographs of injuries of other marine mammal species (e.g., George et al., 1994; 2017; Read and Murray, 2000; Rommel et al., 2007; Azevedo et al., 2008; Bradford et al., 2009; Byard et al., 2012; Moore and Barco, 2013). Marks that likely came from non-anthropogenic sources such as competition, predation, disease, and the physical environment are not included in this paper. Scars appearing to be consistent with anthropogenic sources were classified as five types: puncture, vessel strike, entanglement, research tagging, or research remote biopsy. Scars from permitted research came from satellite tags, flipper bands applied during tagging, biopsy of restrained belugas during tagging, and remote biopsy of free-swimming belugas.

Punctures

Puncture scars were consistent with marks made from bullets (either single bullet or shot pellets; Read and Murray, 2000; Moore and Barco, 2013), harpoons, and arrows. Such scars can vary from single wounds to multiple clusters, and from round to irregularly shaped. Those classified as puncture scars were isolated on the body, deep, and surrounded by relatively clean skin, unlike dispersed, relatively shallow puncture wounds caused by scavengers.

Other indicators of puncture scars were those with a relatively small entrance scar on one side and a larger exit scar on the other, or those with a protruding arrow shaft. Biopsy scars, while technically puncture scars, were categorized separately under research scars. Biopsy scars are shallower than puncture scars, have sharper edges, and are smaller. Furthermore, they can be definitively classified as biopsy scars because they occur on identified individuals who were photographed during the time of biopsy.

Vessel Strikes

Vessel-strike scars were consistent with marks made from blunt trauma from a vessel bow strike or from lacerations made by a propeller. Small-boat propeller strikes typically leave a series of parallel, cupped-shaped marks that are thicker toward the centers (George et al., 1994; Read and Murray, 2000). Each propeller leaves a different shaped mark based on several factors, including trajectory, propeller pitch angle, torque, and speed at impact (Rommel et al., 2007), and scars can be straight, z- or s-shaped, curved, or open in the middle with thin trails (Moore and Barco, 2013). Scars from bow strikes were consistent with external signs of blunt trauma, such as dents, abrasions, and misshapen areas (Moore and Barco, 2013).

Entanglements

Entanglement scars were consistent with marks made from rope, monofilament line, and nets. Entanglement could result during active fishing, or from entanglement in derelict fishing gear and other anthropogenic marine debris. Read and Murray (2000) state that the physical evidence associated with entanglement is specific to each combination of cetacean and fishing gear but that scars from entanglement include indentations and lacerations.

Satellite Tagging

Satellite-tag scars were matched from photographs collected during live-captures of 20 belugas by NMFS-led research teams between 1999 and 2002 (18 of the 20 captured were satellite-tagged). Details about the capture and tagging, including tag types and whale movements during the life of the tags, are presented in Shelden et al. (2018). Belugas in the photo-ID catalog were classified as "confirmed satellite-tagged" individuals if the following types of tag-induced scars were visible in photographs: scars with a distinct shape (circular, crescent-shaped, or band-like); scars in an obvious pattern (depending on the tag type and attachment used in different years, tags caused scars in pairs, trios, or up to five); and/or scars in known tagging locations on the body (details can be found in McGuire and Stephens[5]).

In some cases, scars from biopsies that were taken to determine genetic sex were also visible in photos and were used as additional evidence of a tagging event (biopsy samples were taken with a trocar while whales were restrained during tagging). Individuals with photographs of scars that were similar to confirmed tagging scars but were less distinct in shape, pattern, or placement were classified as "possible satellite-tagged" individuals. Individuals classified as satellite-tagged whales were differentiated from one another based on photographs showing a combination of marks, tag scars, and tag placement, to avoid mistakenly matching similar scar patterns caused by the same tag type.

We verified that the genetic identification of any dead satellite-tagged individuals matched the genetic information from the individuals' tagging samples obtained during the original handling. Although scars from satellite tagging were technically also puncture scars (from tag holes) or entanglement scars (from flipper bands), they were considered separately under research. Flipper bands were placed around either left, right, or both pectoral flippers of tagged whales in 1999 and in 2002, and all catalog and stranding photographs were examined for signs of flipper band attachment or scarring.

Biopsies

Biopsy scars are visible on 20 belugas remotely biopsied by NMFS-led research teams in 2016 and 2017. Details are available in McGuire et al.[6,7] and from Wade[8]. Genetic sex was determined from skin samples, and levels of reproductive hormones (for females) were obtained from blubber samples. Photographs were taken of whales at the time of biopsy in order to match them to previously identified individuals in the 2005–17 photo-ID catalog.

Assignment of Anthropogenic Scar Type Labels to Identified Individuals

Three experienced photo-analysts independently examined all photos (~38,000) of the 78 dual-side whales in the 2005–17 catalog for signs of anthropogenic scars and assignment of scar type. Photo-ID protocols, presented earlier in the methods section, made it possible for an individual to be accepted into the catalog if photos matched across years, even if it did not have a complete profile set of high-quality photos. The exception to the complete profile set requirement was intended for animals that have readily identifiable scars but might not have images of the whole length of the dorsum, with the multiple-year requirement to ensure that the scar was lasting. We therefore reexamined photographic records of the dual-side whales and determined that complete profile sets were available for all 78 dual-side whales, on both sides, with photo-quality sufficient to ensure that any scars within those sections could be seen if present. Analysts also examined photographs of belugas photographed during surveys and strandings that were never identified in the catalog.

The review for anthropogenic scars focused on the dual-side catalog because individuals photo-identified on both sides of their body have the most complete sighting records in the catalog and are therefore the most useful for obtaining information about survival and reproduction. Combining sighting records and associated reproductive histories from both sides of an individual provides a more complete sighting record, and reduces the risk of missing an individual sighting because only one side was photographed in a year, or that a sighting of an individual with a calf was missed because the calf was only observed on one side of the mother.

Scar types were incorporated into the photo-ID database via scar-type labels that were applied to individual photos and later queried to generate summaries of individual whales with particular scar types. A matrix was created of the five types of anthropogenic scars (i.e., puncture, vessel strike, entanglement, satellite-tagging, or biopsy) and each dual-side whale's identification number. Each identified whale was scored as "confirmed" (unambiguous evidence, such as an attached rope), "possible" (ambiguous, the mark also could have been from another source), or "no" (without any evidence of anthropogenic trauma) in

[5]McGuire, T., and A. Stephens. 2016. Summary report: status of previously satellite-tagged Cook Inlet beluga whales. Rep. prep. for Natl. Mar. Fish. Serv., Alaska Reg. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 92 p. (avail. online at https:// 87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/ af2fcb_6a8302766d9544208e9465bce0a928c1.pdf).

[6]McGuire, T., R. Michaud, M. Moisan and C. Garner. 2017. Cook Inlet beluga whale biopsy: field report for 2016 feasibility study. Rep. prep. for Natl. Mar. Fish. Serv., Mar. Mammal Lab., Alaska Fish. Sci. Center and Alaska Reg., Protected Resour. Div. by LGL Alaska Res. Assoc., Inc., Anchorage, AK, 80 p. (online at https://87e3476c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ ugd/af2fcb_1f214afc7d034220a2a2b7b2128be610.pdf).

[7]McGuire, T., A. Stephens, and J. McClung. 2018. Photo-identification of beluga whales in Cook Inlet, Alaska: inclusion of biopsy and hexacopter photographs from 2017. Rep. prep. for Natl. Mar. Fish. Serv., Mar. Mammal Lab. The Cook Inlet Beluga Whale Photo-ID Project, Anchorage, AK, 91 p. (online at https://87e3476 c-d33e-49e9-a267-ef2e5cfaec2e.filesusr.com/ugd/af2fcb_21893dbfcdf344818314477 a3c340c75.pdf).

[8]P. R. Wade. Unpubl. data on file at Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

each of the scar type categories. The location of each scar that had been assigned a "confirmed" or "possible" was then noted, using the sections illustrated in Figure 2, as well as the year in which a scar was first photographed.

Sighting Histories of Individuals with Anthropogenic Scars

Sighting histories (i.e., dates and locations of photographed sightings) were compiled for all belugas in the 2005–17 dual-side catalog who had confirmed or possible signs of anthropogenic scarring. The photo-ID resighting data of individual whales was augmented with biological data (e.g., sex, age, reproductive status) from whales that were photographed during necropsies (Burek-Huntington et al., 2015), satellite-tagging studies (Shelden et al., 2018; McGuire and Stephens[5]), and remote biopsy (McGuire et al.[6]).

Healing Histories

Scar condition was noted throughout an individual's sighting history. Scar condition describes what can be seen in photographs of a scar (from all sources), such as probable infection of the scar, changes in shape, size, and margins of the scars over time, and condition of the area around the scar. The presence of probable infection was inferred from discolored and/or swollen irregular looking tissue in or around the scar(s) (Geraci and Smith, 1990; St. Leger et al., 2018). We also noted visible signs of abnormal body condition (e.g., concavity around head and neck, prominent dorsal ridge, and/or concavity of the dorsal crest over satellite-tag attachment sites (McGuire and Stephens[5]).

Reproductive Histories

Identified belugas were classified as "presumed mothers" (and were therefore presumed to be females) if they appeared in the same uncropped photo frame with a calf or neonate alongside and their association was unambiguous (i.e., there were not multiple adults in close proximity to the calf). When the relationship between an individual calf and individual adult was ambiguous, either because of multiple adults near the calf, little difference in relative color or size, or distances of more than several meters between the adult and the calf, the individual was classified as "possible mother" (and therefore possible female).

Belugas were classified as calves in photos if they were gray, relatively small (i.e., < 3/4 the total length of adult belugas), and photographed near or alongside a larger, lighter-colored beluga. Neonates (i.e., newborns, up to 2 mo old) were distinguished in photographs by visible fetal folds and often a peanut-shaped head (McGuire et al., 2020a). If a presumed mother was seen with a calf in multiple years, and high-quality photos showed the calf clearly appearing progressively larger with respect to its mother in subsequent years, it was assumed to be the same calf maturing over time. We noted if a presumed female had a record of calving before and/or after tagging and biopsy events or estimated dates of anthropogenic trauma.

Survival Histories

We used stranding records and photo-ID records to determine survival, asking the question: how many dual-side whales in the 2005–17 catalog with signs of anthropogenic trauma were still alive in 2017? Unambiguous information on mortality was provided by photographs of carcasses (2005–17) and live individuals in 2017.

We also used cessation of photographic re-sightings to infer if an identified whale was dead by 2017. Time intervals that demarcated a cessation rather than an interruption in re-sights were determined based on the distribution of re-sight frequencies of all whales in the catalog. All photo-ID cataloged whales that had not been seen since 2006 (i.e., more than the maximum gap in the re-sight distribution of 10 years) were presumed dead. We also confirmed that those individuals presumed dead were not later photographed in 2018 or 2019. We then compared survival records according to scar type and sex of affected individuals.

Results

Prevalence of Anthropogenic Scars

We reviewed photographic records of 106 individual belugas, obtained by combining the datasets from the dual-side photo-ID catalog (n = 78) and necropsies (n = 33), including 5 whales that were common to both datasets. In this combined dataset, there were 40 individual belugas (37.7%) with scars that were classified as being of either confirmed (n = 23) or possible (n = 28) anthropogenic origin (these numbers will sum to more than 40 because some individuals had scars in more than one category). Sighting records of 24 individuals with anthropogenic scars attributed to punctures, vessel strikes, and entanglements are summarized in Table 1. Sighting records of 18 individuals with scars attributed to research (biopsies, satellite tagging, and flipper bands) are summarized in Table 2.

In our sample, research scars accounted for the majority of confirmed anthropogenic scars, followed by entanglement scars, and vessel-strike scars (Fig. 3). There were no confirmed puncture scars. Most of the scars classified as possibly anthropogenic appeared to be from possible entanglement or possible vessel-strike, followed by possible puncture. As we later discuss, our sample is biased toward animals with research scars because the dates and source of these scars are known.

In the dual-side photo-ID catalog (n = 78), 15% of individuals had signs of confirmed or possible entanglement, 14% had signs of confirmed or possible vessel strikes, and 5% had signs of possible puncture scars (Table 1). For research scars, 15% of the individuals in the dual-side photo-ID catalog had satellite-tag scars, 9% had scars from remote biopsy, and 3% had flipper-band scarring (Table 2).

Table 1.—Summary of 24 Cook Inlet beluga whales in the 2005–17 stranding and dual-side photo-ID datasets with scars indicative of anthropogenic trauma from entanglement, vessel strikes, and punctures (non-research). n=scar not detected, p=scar possibly detected, c=scar confirmed. COD=cause of death assigned during necropsy, D=denotes photo-ID number, N=necropsy id number. Adults are presumed to be female if they were photographed with an accompanying calf.

ID #	Puncture scar	Vessel-strike scar	Entanglement scar	Trauma source (confirmed or presumed)	Year first identified	Year trauma scar first photographed and status (* indicates scar fresh)	Sex	Female seen with calf post-trauma?	Year last seen	Dead by 2017? (COD)	Wound-site history?
D100	n	p	p	Vessel strike or entanglement	2005	1994 (during NMFS suction cup tagging study)	Presumed female	Yes	2016	No	No
D102	n	p	p	Possible entanglement in line or rope, or ship strike; infection in fold	2005	2005	Presumed female	Yes	2016	No	Infection in folds intermittently throughout sighting history
D106	p	n	n	Gunshot, possible entrance wound right, exit wound left; could also be from orca bite	2004	1994 (during NMFS suction cup tagging study)	Confirmed male	N/A	2013	Confirmed dead in 2013 (COD choked on flatfish)	Infection in holes and folds intermittently throughout sighting history
D107	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D108	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D112	n	n	p	Monofilament line or net	2005	2005	Presumed female	Yes	2017	No	No
D113	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2017	No	No
D1220	n	p	p	Vessel strike or entanglement	2005	2005	Presumed female	Yes	2107	No	Infection in holes and folds intermittently throughout sighting history
D135	n	n	p	Line around tailstock, could also be predation attempt	2005	2015 (body section with scar not photographed before 2015)	Presumed female	Yes	2017	No	No
D14	n	p	n	Vessel strike or predation attempt	2005	2005	Presumed female	Yes	2017	No	No
D195	n	p	n	Vessel strike or predation attempt	2005	2008 (body section with scar not photographed before 2008)	Presumed female	Yes	2017	No	No
D2052	n	n	p	Monofilament line	2005	2005	Presumed male	N/A	2017	No	No
D206	n	c	n	Propeller scars	2005	2005	Presumed female	Yes	2017	No	No
D2303	n	n	c	Necropsy noted old net injury; also confirmed this whale satellite tagged in 2002	2006	2015 during necropsy (not from ID photos)	Confirmed male	N/A	2015	Confirmed dead 2015 (COD severe lung infection, associated infection of tag scar)	N/A (entanglement scars not seen while alive)

Table continued

Table 1.—*Continued.*

ID #	Puncture scar	Vessel-strike scar	Entanglement scar	Trauma source (confirmed or presumed)	Year first identified	Year trauma scar first photographed and status (* indicates scar fresh)	Sex	Female seen with calf post-trauma?	Year last seen	Dead by 2017? (COD)	Wound-site history?
D3846	n	n	c	Heavy braided line visible	2010	2010	Presumed male	N/A	2013	Presumed dead[1]	Rope appears tighter and cutting into flesh more every fall compared to every spring, and with every year
D419	n	n	p	Rope and/or monofilament line	2005	2005	Presumed female	Yes	2017	No	No
D516	p	p	n	Possible gunshot, entrance wound on left, exit wound on right; could also be from vessel strike	2006	2006	Sex unknown	No	2006	Presumed dead[2]	n/a (only photographed 1 day)
D68	n	p	n	Vessel strike, or predation attempt	2005	2005	Presumed female	Yes	2017	No	No
D7244	n	p	n	Necropsy noted possible propeller injury left flank and probable blunt trauma, head and neck	2007	2012* when dead (body section with scar not photographed before)	Confirmed male	N/A	2012	Confirmed dead in 2012 (COD undetermined)	n/a
D75	p	n	n	Possible gunshot: exit wound on right and entrance wound on right; possible satellite tag scar	2005	2005	Presumed female	Yes	2017	No	Infection in scars intermittently throughout sighting history
D85	n	n	p	Rope and/or monofilament line	2005	2005	Presumed female	Yes	2017	No	No
D86	p	n	n	Possible shaft of arrow stuck in skin	2005	2006*	Presumed female	Yes	2017	No	No
N 2017206	p	n	n	Necropsy noted possible trauma to the side and head, possible gun shot with positive metal detection from metal detector, but no metal found	Not photo-identified; no photos	2017* during necropsy	Confirmed female	N/A	2017	Confirmed dead 2017 (COD undetermined, possible gunshot)	n/a
N2012106	n	n	c	Entangled in gill net	Not photo-identified (<2 years old; too young)	2012* during necropsy	Confirmed male	N/A	2012	Confirmed dead 2012 (COD entanglement complicated by malnutrition and a variety of chronic parasitic infections)	n/a

[1]Presumed dead after abrupt end to robust sighting records
[2]Presumed dead after >10 years without resighting

Table 2.—Summary of 18 Cook Inlet beluga whales in the 2005–17 stranding and dual-side photo-ID catalog datasets with scars indicative of anthropogenic trauma from research (biopsy, satellite tagging, and flipper bands). COD=cause of death assigned during necropsy.

Photo-ID # (NMFS biopsy or tagging ID #)	Research scar (confirmed or presumed)	Year beluga first identified in photo-ID catalog	Year trauma scar first photographed and status (* scar fresh)	Sex (confirmed or presumed)[1]	Year whale last seen	Dead by 2017?	Female with calf post-tagging or biopsy (2005-2017)?	Wound sighting history
D16873 (DL-CIB16-32)	Confirmed remote biopsy 2016	2010	2016* during biopsy	Confirmed male	2018	Nc	N/A	Wound closed, no signs of swelling or infection
D154 DL-CIB16-35)	Confirmed remote biopsy 2016	2005	2016* during biopsy	Confirmed female	2018	No	Yes (pregnant at biopsy[2])	Biopsy site not visible when whale photographed days after biopsy
D220 (DL-CIB16-36)	Confirmed remote biopsy 2016	2005	2016* during biopsy	Confirmed female	2018	No	Possible (pregnant at biopsy[2])	Scar seen 2 weeks post biopsy, wound open but did not appear infected or swollen, wound closed by 2017
D19173 (DL-CIB17-02)	Confirmed remote biopsy 2017	2016	2017* during biopsy	Confirmed female	2017	No	No (not seen with calf pre-biopsy either)	Not seen after 2017 biopsy
D2379 (DL-CIB17-03)	Confirmed remote biopsy 2017	2005	2017* during biopsy	Confirmed male	2018	No	N/A	Scar visible in 2018; wound closed, no signs of swelling or infection
D103 (CI-01-0)	Confirmed satellite tag from 2001	2005	2001* during biopsy	Confirmed female	2017	No	Yes	Tag scars conspicuous but no signs of infection in 2017
D2303 (CI-02-05)	Confirmed satellite tag and flipper band	2005	2002* during tagging	Confirmed male	2015	Confirmed dead 2015 (COD severe, chronic bronchopneumonia and secondary infection of tag scar)	N/A	Scars conspicuous, worsening infection of tag holes, body around tag site becoming concave; signs of flipper damage from flipper band;
D111 (CI-00-02)	Confirmed satellite tag	2005	2000* during tagging	Confirmed female	2017	No	Yes	Tag scars inconspicuous and no signs of infection; abrasions across dorsal ridge
D115 (CI-02-08)	Confirmed satellite tag and flipper band	2005	2002* during tagging	Confirmed male	2014	Confirmed dead 2014 (COD live stranding)	N/A	Tag scars conspicuous but no signs of infection; signs of flipper damage from flipper band
D2204 (CI-02-06)	Confirmed satellite tag	2005	2002* during tagging	Confirmed male	2007	Presumed dead	N/A	Scars conspicuous and appeared infected and deteriorating 2005-2007
D243 (CI-01-01)	Confirmed satellite tag	2005	2001* during tagging	Confirmed female	2017	No	Yes	Conspicuous tag scars, one scar appears healed, infection in two scars intermittently throughout sighting history
D49 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Conspicuous tag scar; infection in tag scar intermittently throughout sighting history
D549 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Tag scars conspicuous but becoming smaller over time; no signs of infection
D875 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed male	2017	No	N/A	Tag scar inconspicuous and becoming smaller over time; no signs of infection
D403 (unable to match)	Confirmed satellite tag, tag year unknown	2005	2005	Presumed female	2017	No	Yes	Conspicuous tag scar; infection in tag scar intermittently throughout sighting history
D3024 (unable to match)	Confirmed satellite tag, tag year unknown	2009	2009	Presumed female	2017	No	Yes	Tag scar conspicuous but no signs of infection
D5319 (unable to match)	Confirmed satellite tag, tag year unknown	2007	2007	Presumed female	2017	No	Yes	Tag scar conspicuous but no signs of infection
D75 (unable to match)	Presumed satellite tag, tag year unknown; presumed gunshot	2005	2005	Presumed female	2017	No	Yes	Conspicuous scars; infection in scars intermittently throughout sighting history

[1]Genetic sex from satellite tag samples determined by Greg O'Corry-Crowe, Florida Atlantic University; genetic sex from biopsy samples determined by Nick Kellar, NMFS Southwest Fisheries Science Center, and Kim Parsons, NMFS Northwest Fisheries Science Center.

[2] Pregnancy status at biopsy determined from hormones by Nick Kellar, NMFS Southwest Fisheries Science Center.

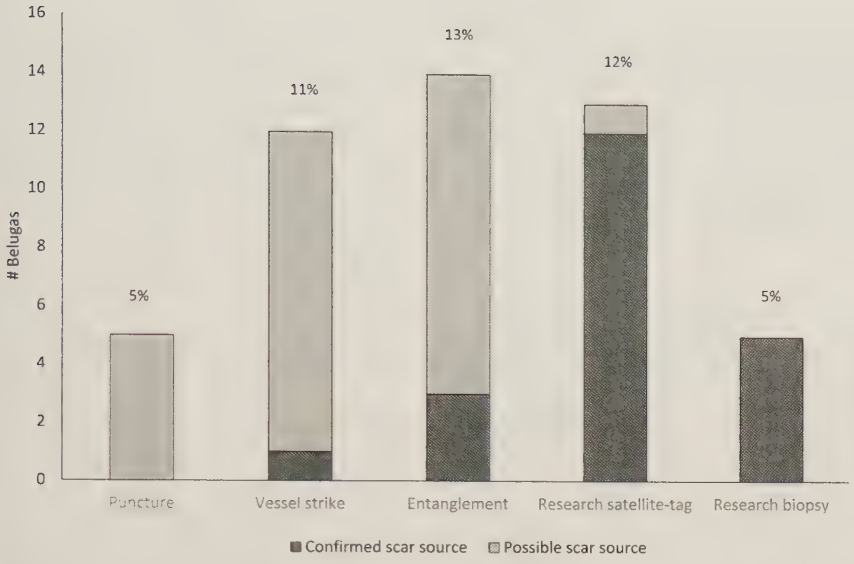


Figure 3.—Number of individual Cook Inlet beluga whales from the combined 2005-17 dual-side photo-ID catalog and necropsy datasets with signs of anthropogenic scars, according to scar type (i.e., punctures, vessel strikes, entanglement, or research). Of 106 whales examined, 24 had signs of anthropogenic scarring. Numbers are not additive across scar types as some individuals had scars of more than one type. Numbers above each bar refer to the percent of the total sample that had confirmed or possible scars from each source.

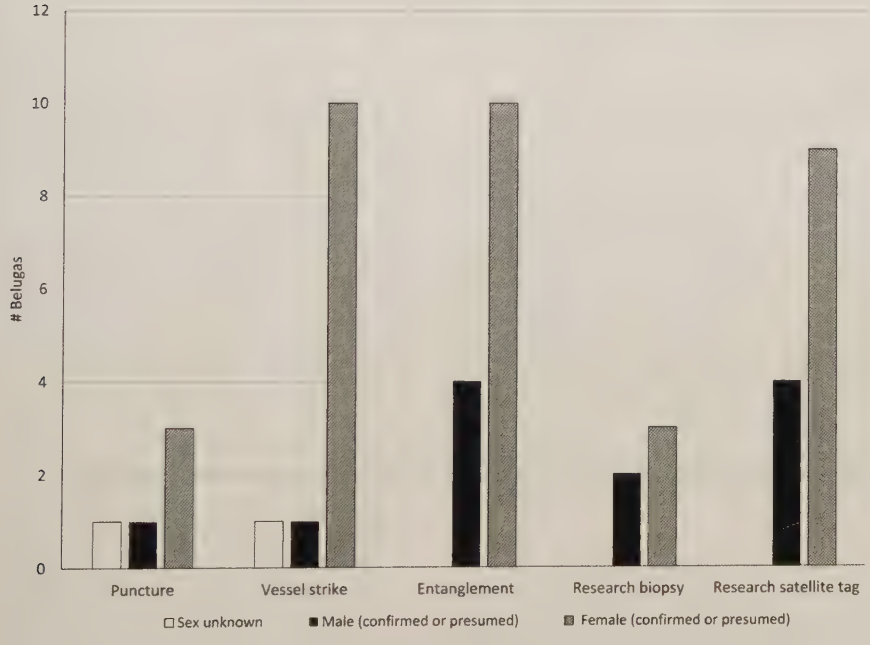


Figure 4.—Sex of individual Cook Inlet beluga whales from the combined 2005-17 dual-side photo-ID catalog and necropsy datasets with signs of anthropogenic scars, according to scar type (i.e., punctures, vessel strikes, entanglement, or research). Numbers are not additive across scar types as some individuals had scars of more than one type. Whales in the confirmed and possible scar type categories have been combined.

Out of the 33 necropsied belugas, two (6%) had scars from satellite-tagging (both tag scars and flipper band scars), two (6%) had signs of entanglement, one (3%) had possible signs of a vessel strike, and one (3%) had possible signs of puncture scars consistent with gunshot wounds (Table 1, 2). In the majority of the necropsy cases of individuals with anthropogenic scars, COD was attributed to something other than the confirmed or possible source of the scar (e.g., an individual with healed satellite-tag scars who died from aspiration of muddy water after live-stranding). There were no cases in which COD was confirmed to be from anthropogenic trauma. There were three cases in which COD was listed as undetermined but of possible anthropogenic origin: possible vessel strike (n = 1; 3%), possible gunshot (n = 1; 3%), and possible entanglement (n = 1; 3%).

In the combined photo-ID and necropsy datasets there were more females than males in each of the scar-type categories (noting some whales fell into more than one category; Fig. 4). However, considering the necropsy dataset separately, there were more dead males with confirmed or possible anthropogenic scars than dead females (Table 3).

Puncture Scars

Four of the five possible puncture scars may have been from gunshot wounds, based on patterns of presumed entrance and exit wounds on opposite sides of the body (Table 1; Fig. 5). All of the possible gunshot scars visible in the first year individuals were photographed and persisted throughout their sighting histories. None of the possible gunshot wounds were fresh when first photographed. The fifth beluga with a possible puncture wound had what appeared to be an arrow protruding from one side. The possible arrow was not seen when the whale was photographed a month prior and was also not seen on the whale when it was photographed again six days later.

Table 3.—Number of dead (confirmed or presumed) Cook Inlet beluga whales with scars indicative of anthropogenic trauma, according to scar type (confirmed and presumed) and sex (confirmed and presumed). Presence of a scar type on a carcass does not necessarily mean that it was the cause of death (COD).

Anthropogenic scar type (confirmed and presumed)	No. of belugas	No. confirmed dead	No. presumed dead	No. dead (confirmed and presumed)	% of all 11 dead (confirmed and presumed)
Puncture	5	2 (1 male, 1 female)	1 (sex unknown)	3	27%
Vessel	12	1 (male)	1 (sex unknown)	2	18%
Entanglement	14	2 (male)	1 (male)	3	27%
Biopsy	5	0	0	0	0
Satellite tag	13	2 (male)	1 (male)	3	27%

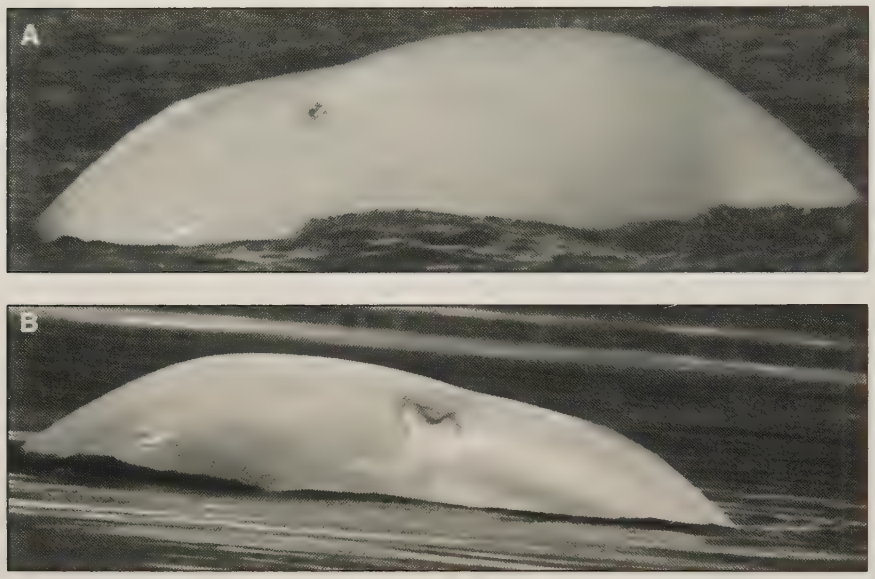


Figure 5.—Beluga D75, with possible puncture scars. The scars may be from a gunshot, with the possible entrance wound on the left side (A) and the possible exit wound on the right side (B). It is also possible these scars were made from a satellite tag, although the scar pattern and location do not match those from the confirmed satellite tags.

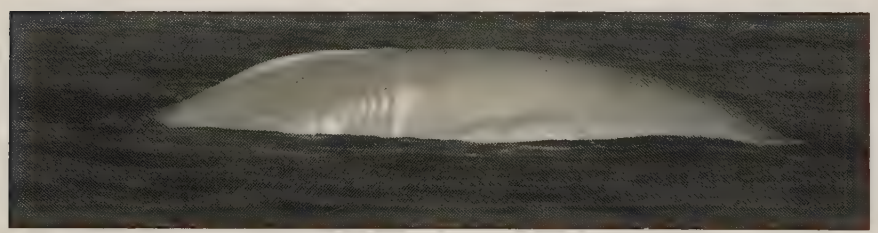


Figure 6.—Beluga D206, with a confirmed propeller scar along its right side.

There were three females with possible puncture scars vs. one male. All of the females with possible puncture scars were observed with calves that would have been born after they were first photographed with a puncture scar. Three whales with possible puncture scars were later confirmed or presumed dead (Table 3). In the case of one confirmed dead whale, necropsy determined the COD was from choking on a large flatfish (Rouse et al., 2017).

Vessel-strike Scars

The one case of a confirmed vessel strike showed clear signs of propeller marks along the right flank of the live whale (Fig. 6). These propeller scars were already healed when the whale was first photographed in 2005, and they did not appear to change in later years. Ten belugas had signs of possible vessel strikes in photographs taken while they were alive, but these marks could also have been made by entanglement (Fig. 7, 8), predation attempts, or shotgun blasts that damaged large areas of tissue (similar to being struck by the bow of a vessel). Most of the confirmed or presumed vessel-strike scars were on females (Fig. 4). All of the females with vessel-strike scars were observed with calves that would have been born after they were first photographed with the scar (Table 1).

Two whales with possible vessel-strike scars were later confirmed or presumed dead (Table 3). One was a male and one was of unknown sex. The dead male had fresh signs of a possible vessel strike that were detected during necropsy, with the examining veterinarian (co-author KBH) noting possible propeller injury on the left flank and probable blunt trauma on the head and neck; all areas of the body that wouldn't have been photographed while the whale was alive. The COD for this male was listed as blunt trauma from possible ship strike (McGuire et al., 2020b).

Entanglement Scars

There were three cases of confirmed entanglement. We documented one live whale entangled in heavy, braided line (Fig. 9). This whale was already entangled when it was first photographed throughout the 2010 field season and was photographed annually through 2013. NMFS and the Alaska Marine Mammal Stranding Network were updated annually with sighting information and photographs of this entangled whale. Based on how frequently this whale was seen during 2010 through 2013 and the abrupt cessation of sightings post-2013, it is assumed this whale died undetected. It is also possible it became disentangled and was no longer recognized; howev-

er, the identification marks (i.e., marks other than the line) were quite distinct on this whale, and it seems likely it would still have been recognized if it had been photographed without the entanglement.

The second confirmed entanglement was encountered when necropsy of a dead, previously satellite-tagged whale, D2303, revealed it also had signs of old net injuries on the flukes, which were not visible in photos of the whale while it was alive. The third beluga confirmed to have been entangled was a young male found dead in a gillnet near the mouth of the Kenai River, and fisheries interaction (entanglement) was noted as the COD, complicated by malnutrition and a variety of chronic parasitic infections (Burek-Huntington et al., 2015). A live beluga was photographed in 2005 entangled in what may have been a tire or a culvert liner but was never resighted or photo-identified and is not included in Table 1 (Fig. 10).

The belugas with signs of possible entanglement ($n = 11$) displayed marks that could have been made from monofilament line or rope around the body or tailstock, and none of these marks appeared to be fresh (Fig. 7, 8). Possible entanglement scars differed from tooth-rake marks in that possible scars from monofilament line were thinner and straighter than tooth-rake marks, and scars from other types of line were wider with rougher edges. Most of the entanglement scars were on females, although the three dead individuals with confirmed or possible entanglement scars were confirmed or presumed male. All of the females with signs of entanglement were observed with calves that would have been born after they were first photographed with the scarring (Table 1).

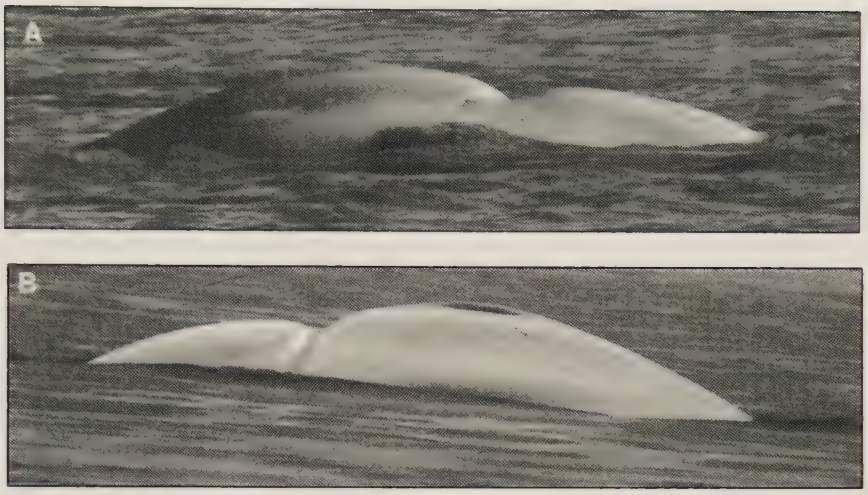


Figure 7.—Left (A) and right (B) sides of beluga D100, with scars possibly from entanglement, vessel strike, or both.

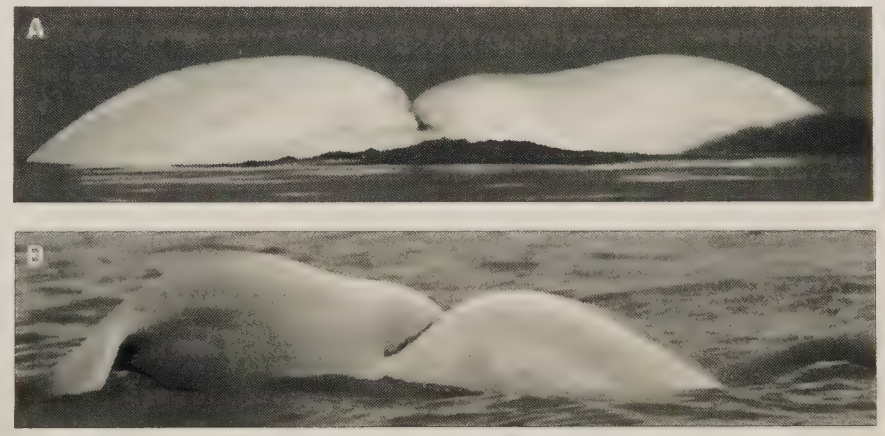


Figure 8.—Left (A) and right (B) sides of beluga D102, with a scar classified as possible entanglement or possible vessel strike. Note the infection in the scar folds in both photos, which occurred intermittently throughout the sighting history of this whale.

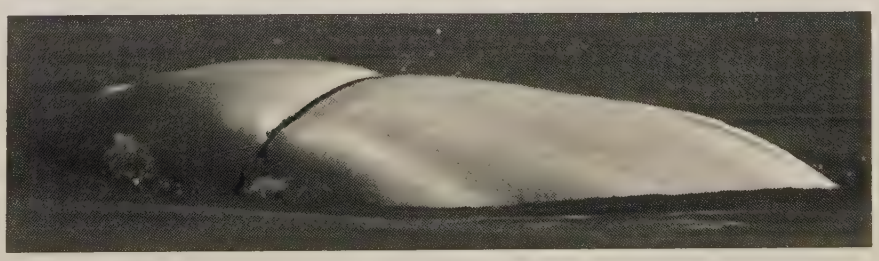


Figure 9.—Left-side photographs of beluga D3846, entangled in heavy braided line.

Biopsy Scars

All 20 belugas remotely biopsied in 2016 and 2017 were also identified individuals in the photo-ID catalog. Five of these were identified individuals in the dual-side catalog; two were males and three were females. There is no evidence that any of these individuals

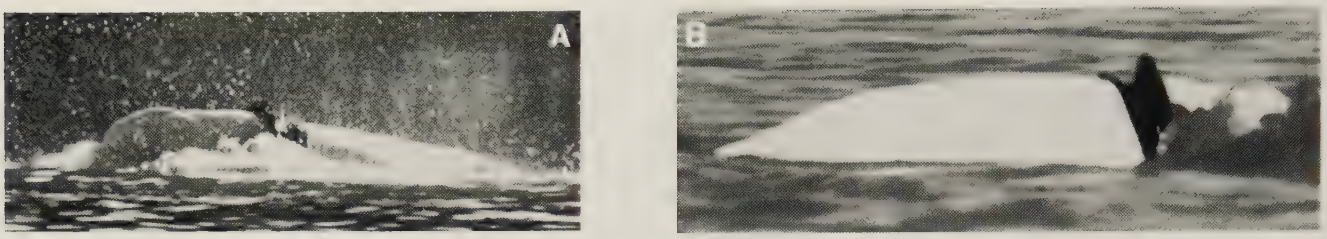


Figure 10.—Left (A) and right (B) sides of an unidentified entangled beluga whale, only seen on one occasion. The object causing the entanglement remains unknown but may be a culvert liner or tire.

have since died. Four of the five dual-side individuals were photographed on days and years following biopsy, and none had signs of infected biopsy scars (Table 2; Fig. 11).

Satellite-tagging Scars

Twelve of the 20 whales captured for satellite-tagging were identified in the dual-side photo-ID catalog. Scars on a 13th individual in the dual-side catalog may have been from a satellite-tag, although the scarring also could have been caused by gunshot wounds. Confirmed satellite-tag scars ranged from conspicuous to almost undetectable in photos of belugas in the photo-ID catalog.

Seven of the 12 (58.3%) dual-side satellite-tagged belugas had no signs of infection throughout their sighting history (e.g., Fig. 12, 13). Beluga D111, satellite-tagged in 2000, is an example of satellite-tag scars that were inconspicuous and without signs of infections (Fig. 12). Beluga D115 (Fig. 13, and Figure 16D) is an example of satellite-tag scars that were conspicuous but showed no signs of infection (shown both in photos while alive and during necropsy). Beluga D115 was tagged in 2002 and photographed annually during the period 2006–14. This male beluga was found dead with an unidentified dead adult female in 2014, possibly following a live stranding event as compacted, aspirated mud was found in their lungs (Shelden et al., 2019b; McGuire et al., 2020b).

Three tagged belugas (25%) appeared to have possible intermittent infections within the indentations and folds made by the tag scars, although the scars themselves appeared healed.

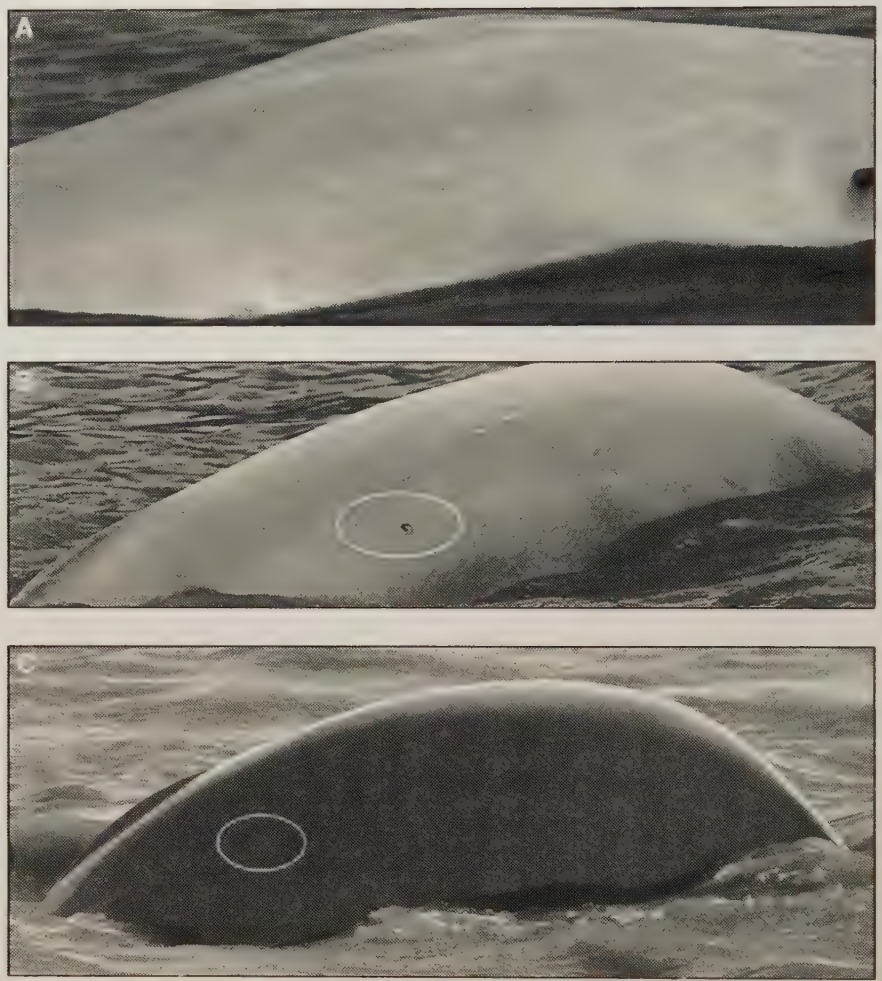
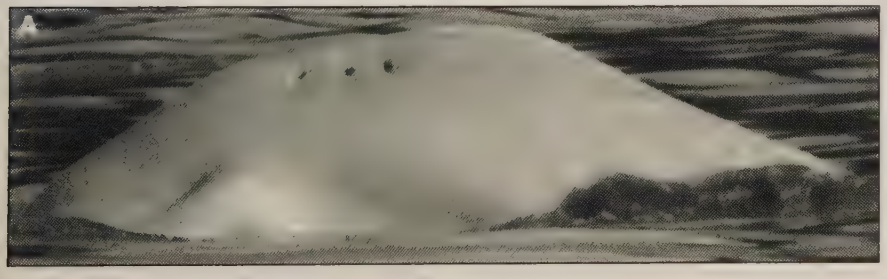


Figure 11.—Left side of beluga D220, showing (A) the biopsy dart location in 2016, (B) the biopsy scar two weeks later, and (C) the closed biopsy scar one year later. (Photo (A) courtesy of Robert Michaud, GREMM, photo (B) courtesy of Marc Webber, U.S. Fish and Wildlife Service).

Over the years, the appearance of the scars in these cases changed to include accumulation of debris within the scar borders, irregularities to scar edges, roughening of the scar surface, and changes in surrounding skin (Fig. 14B, C, D, 15A).

Two tagged belugas (16.7%) appeared to have possible progressive tag-scar infections coupled with de-

Figure 12.—Left side of beluga D111 photographed in 2005 (A), with scars from a satellite tag attached in 2000 (B). This is an example of inconspicuous and uninfected tag scars. (Photo (B) courtesy of NMFS).



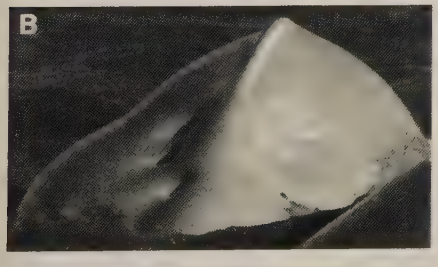


Figure 13.—Beluga D115, satellite tagged in 2002, showing scars on the left side (A) and spanning both sides (B). This is an example of conspicuous but uninfected tag scars. This beluga died in 2014, with cause of death attributed to live stranding.

teriorating body condition and death (one confirmed and one presumed death; Fig. 14, 15). Beluga D2303 was found dead in 2015 and had been satellite-tagged in 2002. Photo-ID photographs of this male showed that the conspicuous satellite-tag scars appeared to become infected in 2006 and worsened yearly thereafter, with the tag holes not only discoloring and deteriorating, but the dorsal area above the tag scars also becoming more concave each year (Fig. 14). At the time of the necropsy, the examining veterinarian (KBH) noted the infection of the tag site and the poor body condition of the whale.

Following histopathological examination of the tissues, the COD was determined to be severe lung infection leading to secondary infection of the tag scars. This was due to the lung infection being oriented around the airways with chronic inflammation, instead of a multifocal random pattern suggesting blood-borne infection to the lungs, such as would be expected if the tagging site was the site of the primary infection. A possible mechanism for secondary infection of the tag site could have been the presence of foreign material in the tagging site acting as a nidus for infection. The finding of refractile material in the tag lesion is suggestive of this. It is also possible the animal suffered from immune deficiency, however this cannot be determined through post-mortem examination. Beluga D2204 was also satellite tagged in 2002 and was photographed with infected and deteriorating tag scars (Fig. 15). A lack of photographic resightings after 2007 indicate this male may have died.

Flipper bands were placed around one or both pectorals of belugas during satellite tagging in 1999 and in 2002 (Shelden et al., 2018). Signs of pectoral-fin damage from the bands were visible in photographs taken during necropsy of the two dead satellite tagged whales (Fig. 16). One of these whales (D115) was photographed alive in 2007 with the band embedded in a damaged pectoral fin protruding from

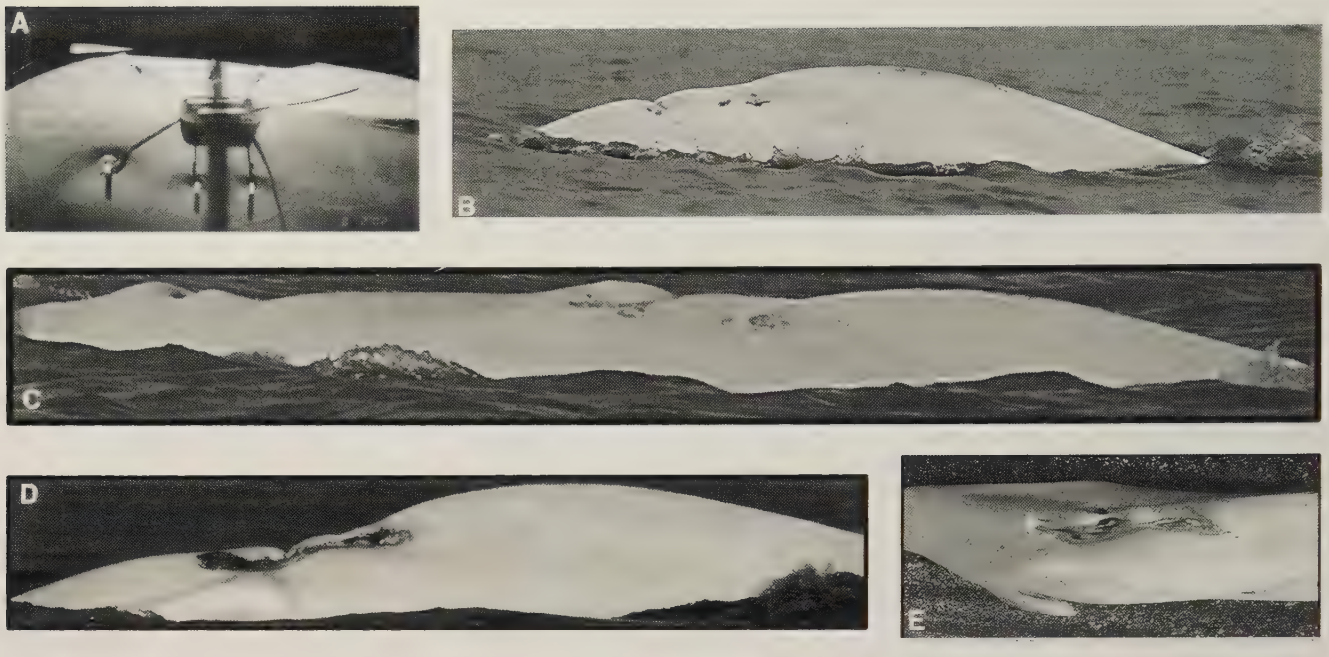


Figure 14.—Beluga D2303, satellite tagged in 2002 (A), with tag scars that were conspicuous, infected, and deteriorating. Left side in 2007 (B); 2011 (C) and 2014 (D), with progressive tag site deterioration, and increased concavity along the front of the dorsal ridge. This beluga died in 2015 (E), with cause of death attributed to severe lung infection, with associated infection of the tag scars. (Photo (A) courtesy of NMFS, photo (C) courtesy of Randy Standifer and the Alaska Marine Mammal Stranding Network).

the water while it swam on its side (Fig. 16B).

Discussion

Our analysis found that anthropogenic activities identified in the CIBW Recovery Plan as potential threats to the population (i.e., entanglement, vessel strikes, and trauma from research) are in fact experienced by belugas in Cook Inlet. Over a third of the individuals in our dataset bore scars from confirmed or possible anthropogenic injury, and 9% of necropsied whales had uncertain causes of death that were potentially related to anthropogenic-induced trauma. While our data clearly demonstrates that anthropogenic injury occurs with some frequency in the CIBW population, using our findings to quantify anthropogenic injury at the population level, and inferring the population-level consequences of these injuries is more difficult.

Although the dataset has limitations for such quantitative inference, it enables us to provide a qualitative assessment on the incidence of anthropogenic injury in the entire CIBW population. Specifically, we discuss how some anthropogenic impacts are not detected in our sample, but also how our sample of individuals (n = 106, dual-side photo-identified individuals plus necropsied individuals) may not be representative of the entire CIBW population. We also discuss the sources of anthropogenic trauma in relation to other beluga populations and other whales to give a broader context to our findings.

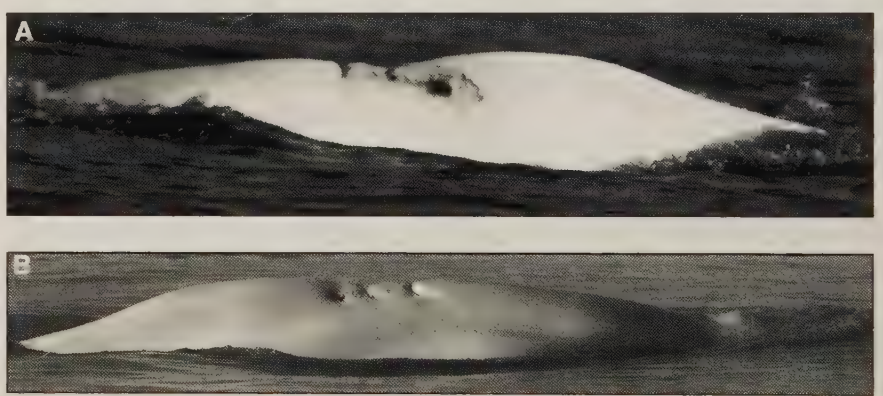


Figure 15.—Beluga D2204, satellite tagged in 2002, showing scars on the left side (A) and right side (B). This is an example of conspicuous and deteriorating tag scars. A lack of resightings after 2007 indicated this whale may have died.

Missed Anthropogenic Impacts

The scars documented in our dataset likely do not represent all anthropogenic impacts to the whales in our sample because some impacts are not seen for various reasons. Healed and incon-

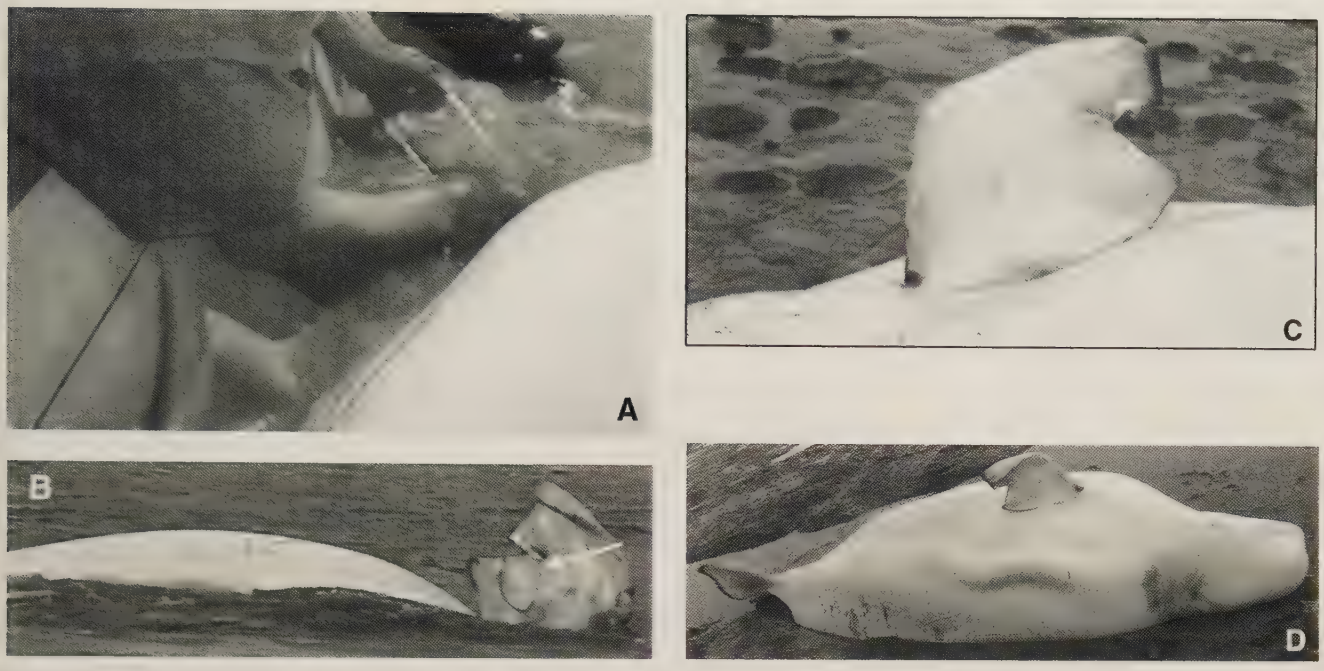


Figure 16.—Flipper bands were placed around one or both pectorals during satellite tagging in 1999 and 2002 (A). Photo (B) shows a flipper band in 2007 embedded in a damaged left-pectoral fin. Photos (C) and (D) show damage from flipper bands on dead beluga D115 (assigned name CI-0208 during tagging) in 2014. (Photo (A) courtesy of NMFS, photo (B) courtesy of Chris Garner, photo (D) courtesy of Bill Streever).

spicuous scars may be missed in identification photos and during necropsy. For example, the satellite-tag scars on D111 (Fig. 12) were only seen in photos from early in its resighting history and not in later photos. Had only the more-recent photographs been available, these satellite-tag scars would not have been detected. Because all photo-ID surveys and 96% of all reported strandings occurred during the ice-free months (April–October), any fresh anthropogenic scars and/or related mortalities occurring November through March would likely be missed in both the datasets.

Additionally, marks on most body sections of live belugas are missed during photo-ID. Because only certain body sections of free-swimming belugas are visible above the turbid water, any scars on normally submerged body sections are not detected unless the beluga is later encountered stranded or dead onshore. For instance, there were four belugas whose anthropogenic scars were only detected when normally submerged sections of their bodies were visible during necropsy.

Anthropogenic scarring is likely underestimated in the necropsy records. Delays between initial detection and necropsy may prevent examinations from being conducted while carcasses are still fresh, during which time signs of anthropogenic scars may decompose or be destroyed by scavengers, lessening the probability of detection, or the degree of confidence assigned by the examiner. Additionally, beached and floating carcasses usually have only one side visible and are too heavy to roll, so any scars on the non-exposed side of the body will be missed, especially on larger whales.

Sample Bias

Our analysis indicated that 17% of examined belugas bore scars from research, 13% exhibited signs of confirmed or possible entanglement, 11% had signs of confirmed or possible vessel-strikes, and 5% had possible puncture scars. While we likely miss some indications of anthropogenic trauma as discussed above, we cannot simply use our estimates as minimum prevalence rates within the population because our sample is unlikely to be representative of the entire population.

Anthropogenic scarring is more likely to be detected on older belugas than younger ones. The photo-ID catalog, particularly the dual-side catalog, is biased toward well-marked older individuals because they have had more time to accumulate identifiable marks over time, including anthropogenic scarring. In addition, younger whales have a faster-growing dermis and epidermis (Reeb et al., 2005). Therefore nonlethal scars obtained from anthropogenic trauma would likely heal faster and be less visible on younger whales than on older ones. At the same time, younger, smaller belugas may be more likely to die as a result of anthropogenic injury from vessel strikes or gunshots.

Younger belugas might also be less likely to break free of entanglements because they are weaker than larger belugas. If younger carcasses sink faster because of less body fat or are more rapidly destroyed by scavengers because of their relatively smaller size,

then this part of the population (i.e., younger whales killed by anthropogenic activities) may be especially underrepresented in our analysis. These age-related factors, and how they relate to anthropogenic trauma, are complicated and suggest that our sample may overestimate anthropogenic trauma within the population as a whole due to a disproportionate number of older animals in the catalog, while at the same time underestimating anthropogenic impacts in younger animals.

Research was the most common cause of all anthropogenic scarring that we documented, occurring in 16% (n = 17) of our combined photo-ID and necropsy sample (n = 106); 11% were satellite-tag scars and 5% were biopsy scars. Because satellite-tagging scars can be more obvious than other types of scarring and more easily linked across both sides of a whale, satellite-tagged whales were more likely to be in our dual-side sample than whales that had not been tagged. In addition, photographs were available of several of the individuals when they were tagged, and we intentionally tried to find matches to them in the catalog. To date, a total of 18 whales have been satellite tagged, representing about 6% of the most-recent estimated population size of 279 in 2018 (Wade et al.[2]), and about 5% of the population of 357 whales estimated in 2003 (Hobbs et al., 2015a). On the other hand, we know that there were 20 whales remotely biopsied during 2016–17, which would be 7% of the estimated population in 2018, slightly more than the 5% prevalence of biopsy scars estimated with our methods.

Similarly, our methods may underestimate some types of non-research anthropogenic scars more than others because different sources of anthropogenic trauma are more likely to produce scars on different body sections. For example, scars from collisions between vessels and baleen whales are primarily found along the back and dorsal ridge (Bradford et al., 2009), and we would expect the same pattern for belugas based on our field observations of beluga surfacing behavior, including around vessels. In contrast, entanglement scars are more likely to occur on the caudal peduncle, flippers, back, or head (e.g., George et al., 1994; Read and Murray, 2000). Because images used for beluga photo-ID must include the dorsal and adjacent sections and rarely capture the head, flippers, or flukes, we would expect photos in the catalog to underestimate entanglement rates relative to vessel-strike rates.

Prevalence of Anthropogenic Trauma Scars According to Likely Scar Source

Vessel-strike scars included blunt trauma from impact and lacerations from propellers. We were unable to determine the type of vessels involved in the scarring we observed. Large ships and small vessels regularly transit near beluga whales in Cook Inlet and most often approach whales unintentionally. Watercraft observed around belugas during photo-ID surveys included container ships, cruise ships, tugs, barges, dredges, small recreational boats, seismic vessels, U.S. Coast Guard vessels, research vessels, stand-up paddleboards, and windsurfing boards.

During photo-ID surveys, we observed (and reported to law enforcement) several instances in which belugas were intentionally approached by vessels (i.e., boat drivers/occupants were seen pointing at belugas prior to approach), including at the Port of Anchorage small boat launch when a skiff of duck hunters approached a group of whales, and in the Kenai River when a small recreational vessel drove at high speed directly over a small group of belugas in shallow (< 2m) water. We also noted many occasions in which vessels appeared to pass through or over groups of belugas without realizing they were there.

Worldwide, entanglement in fishing gear is the most common source of anthropogenic mortality for small cetaceans (Read and Murray, 2000; Brownell et al., 2019). While we documented several entanglement scars that were apparently nonlethal and one mortality attributed to entanglement, our analysis supports Moore et al. (2000) who stated that direct mortalities from fishing gear, while known to occur, are probably uncommon for belugas in Cook Inlet. Moore et al. (2000) based their conclusions on no reports of mortality or serious injury being recorded by an observer program in 1999 and 2000. Potential sources of entanglement for belugas in Cook Inlet include set nets along shore, drift nets in deeper water, recreational fishing from shore and small vessels, derelict gear (line, nets), and debris. Unfortunately, unless the gear was still present, we were unable to determine the type of gear involved in most entanglements.

For a puncture scar to be confirmed as gunshot or arrow, the event would have to be witnessed, or the bullet or arrow retrieved from the carcass during a necropsy. None of the signs of puncture wounds could be confirmed, and therefore their prevalence is likely underestimated. For example, shotgun blasts can provide a variety of wounds depending upon the power of the shotgun (gauge), shell size, load (birdshot to buckshot to slugs), and distance to target, complicating the assessment of gunshot wounds. In addition, puncture wounds, even when healed, are often exploited by scavengers post-mortem, complicating classification and diminishing examiner certainty.

The possible puncture scars that were noted may have occurred during subsistence harvest (i.e., belugas that were "struck and lost" during past legal subsistence hunting that ended in 2006), poaching (illegal hunting post-2006), and intentional harassment (shooting at whales with the intent to harm or scare rather than to harvest for consumption). The CIBW Recovery Plan[1] notes that since 2006, the NMFS Office of Law Enforcement has investigated credible reports (number and details of incidents not stated) of what appeared to be fresh gunshot injuries to CIBW's, indicating that poaching and/or intentional harassment may still occur.

The potential for illegal harassment of belugas appears to be high along

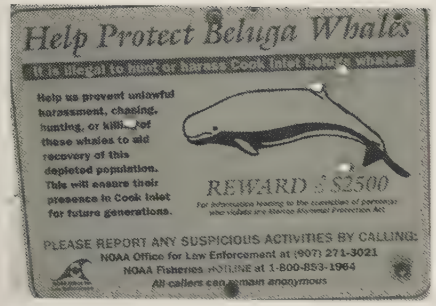

Help Protect Beluga Whales
Help us prevent unlawful harassment, chasing, hunting, or killing of these whales to aid recovery of this depleted population. This will ensure their presence in Cook Inlet for future generations.
REWARD $2500
PLEASE REPORT ANY SUSPICIOUS ACTIVITIES BY CALLING:
NOAA Office for Law Enforcement at (907) 271-3021
NOAA Fisheries HOTLINE at 1-800-853-1964
All callers can remain anonymous

Figure 17.—Photo of one of the many signs about belugas around Cook Inlet with bullet holes.

roadways, where belugas often approach within several meters of shore, as we have noted while photographing belugas from vehicle pullouts on the Seward Highway along Turnagain Arm. Many of the educational signs about belugas along the Seward Highway are riddled with bullet holes (Fig. 17). In addition, a pile of ammunition casings was encountered at the water's edge along Turnagain Arm during a land-based photo-ID survey.

Anthropogenic Trauma Scars and Survival

The CIBW Recovery Plan[1] states that photographs of belugas with healed anthropogenic scars were evidence that some individuals survived traumatic events, and therefore the NMFS classified unauthorized take as a threat of medium, rather than high, concern. We believe this assigned ranking does not consider the low carcass recovery rate (McGuire et al., 2020b) and resulting difficulty in determining how many belugas die of anthropogenic trauma. In addition, although an individual may survive the traumatic event in the short-term, we believe the previous statement ignores the possibility that the individual's long-term survival and/or reproductive output may decrease. Subsequently, this would have a delayed, but important, impact on the overall population size and trajectory.

Moore and van der Hoop (2012) present examples of cetacean entanglements that were not immediately lethal, but ultimately resulted in infection, hemorrhage, and tissue damage, as well as individual pain and suffering, all of which may eventually lead to decreased reproduction and/or survival. A population viability analysis conducted by NMFS determined that even one additional death annually can negatively affect the viability of the population and increase the risk of extinction (Hobbs et al., 2015b).

Anthropogenic trauma can affect beluga health and survival over an extended period. Although anthropogenic trauma was only conclusively established as the primary cause of death for one animal, we use the sighting history of whales that were satellite-tagged to illustrate how anthropogenic trauma can affect beluga health and survival over an extended period, despite signs of individual recovery. Considering the entire period from when satellite tagging began in 1999 to the end of our photo-ID and necropsy analysis in 2017, 3 of the 18 tagged belugas were confirmed to have died, and an additional 5 were presumed to have died. In this example, the mortality rate is 40%. Whales tagged in 2002, when larger bores and tag pins were used (Shelden et al., 2018), died at a higher rate than whales tagged in other years, although none died immediately after tagging. Flipper bands had been used on other beluga populations without incident (Orr et al., 1998; Shelden et al., 2018) but were documented to have caused extreme flipper damage to the two dead CIBW individuals on which they were photographed.

These patterns raise important questions about the impacts of anthropogenic trauma on CIBW's that our data cannot fully resolve but should be considered. For example, did the tagging injuries and/or stress of capture compromise their immune systems, leaving them more vulnerable to later infection and poor overall health or poor body condition? Did the large scars created by tagging allow pathogens already in the environment to become established in their systems? Have rising summer water temperatures in Cook Inlet, documented during our work over the last decade (McGuire[9]), contributed to an increase in scar infection rates? Is there some characteristic(s) of the immune systems of CIBW's, or the environment of Cook Inlet, in which established tagging protocols caused more harm to CIBW's than to belugas in other populations?

We use the previous example not to single out research activities, but rather because our records are strongest for research-related scarring, due to known date and type of anthropogenic activity and the relatively large sample size compared to other types of anthropogenic scarring. We are unable to compare the relative lethality of non-research anthropogenic trauma (i.e., entanglement, puncture, and vessel strikes), because both the number of individuals that have died of a type of trauma and the incidence of the trauma type in the population are unknown. We would also expect that individuals who have survived but bear scars of entanglement, puncture, and vessel strikes may still suffer long-term negative effects of these human interactions, such as chronic infections or reduced ability to feed effectively or escape predators.

For example, one live presumed female has scars indicative of entanglement or vessel strike (Fig. 8). Although she was photographed year after year and is believed to be a reproductive female due to the close accompaniment of different calves over the years, her injury appears to cause labored swimming. Her body twists with her tail coming out of the water with almost every fluke stroke, and she is almost always lagging slightly behind any group with which she is associated. Although she is surviving and apparently giving birth to and raising calves, it is unclear whether her injury may affect her in indirect ways. We do not know, for example, whether her injury may make her more susceptible to killer whale predation, if the increased energy expenditure to swim in an apparent inefficient manner results

[9]McGuire, T. Unpubl. data on file at Cook Inlet Beluga Whale Photo-ID Project, Anchorage, AK 99515.

in chronic stress and increased risk of infection, or if her reproductive rate is lower than it would have been otherwise.

Anthropogenic Trauma Scars and Reproduction

Aside from the obvious link that a dead female is no longer available to reproduce, we were unable to detect associations between anthropogenic scarring and reproductive success in the known females (from biopsy and stranding) and presumed females (inferred from photographs of calf records). We could only examine this on a very basic level, asking if a female was still seen with a calf (that was presumed to be hers) after an anthropogenic scar was acquired. In all cases the answer was yes – all known females were seen with a calf or calves (across multiple years) subsequent to documentation of a scarring event. We do not yet have enough information about individual reproductive rates to determine if reproductive success changed after a scarring event, or how reproductive rates of scarred females compared to non-scarred females.

Our findings show a clear pattern of more females than males having scars indicative of anthropogenic trauma. In contrast, of the animals found dead, more males than females had signs of anthropogenic scarring (although the source of the scarring was not necessarily the COD). There does not appear to be a sex-bias in the greater stranding dataset (McGuire et al., 2020b), or in the photo-ID catalog (McGuire et al.[4])—there are currently 45 individuals of known sex in the photo-ID dual-side catalog and 23 are females and 22 are males. Observations of live males and females in the field show they are found in the same groups and use the same habitat at the same time during the ice-free field season (McGuire et al., 2020a).

We can only speculate as to why there are differences in observed sex ratios with respect to anthropogenic scarring and death. Observations of other beluga populations suggest that pregnant females move more slowly and are less agile (Quakenbush[10]), which may make them more susceptible to vessel-strikes, entanglement, and capture for satellite tagging. Alternatively, or in addition, females may be more susceptible to injury if their attention is on their calves, if they are protecting their calf, or if females with dependent calves are less able to move out of harm's way.

Perhaps females do not heal as well as males if their energy is being used for pregnancy and lactation. During photo-ID surveys, some calves appear to be more curious about vessels, approaching them at closer distances than older animals, which may cause mothers to be drawn closer to boats and nets because of their calves. Adult males may also be experiencing other stressors (e.g., the accumulation of contaminates, which adult females offload into their calves while nursing) (e.g., Shelden et al., 2018) that leave them with compromised immune systems which may make them more susceptible to death when they do experience anthropogenic injuries.

Conclusions

Necropsy data provided information on the prevalence of lethal anthropogenic injury (when noted as the confirmed or possible COD), as well as documentation of anthropogenic scarring only visible upon examination of a carcass (even when not the COD). Photo-ID data provided information about nonlethal prevalence of anthropogenic scarring on living whales, healing/infection of scars, and the life history context for identified carcasses with anthropogenic scars. In addition, the photo-ID data provided information about potential links between anthropogenic scarring and whales that are presumed dead but were not present in the necropsy data.

Combining data from the photo-ID catalog and necropsy reports forms a more complete picture than presented by either dataset alone and allows for estimation of the prevalence of anthropogenic trauma scars according to likely scar source. While the combined datasets maximize what can be learned about anthropogenic trauma, they underestimate prevalence, particularly for extreme trauma where death may be immediate and undetectable with the methods used.

One important result from our study is that anthropogenic trauma effects may take years to manifest. For example, some past research activities, although perhaps not a substantial contribution to anthropogenic mortality in terms of absolute numbers, had unforeseen consequences, including injury from tagging activities and reduced body condition possibly due to tagging which were not apparent until 5 years or longer after the research event. Caution is therefore warranted when implementing or permitting new research techniques for this population, and concerns must be balanced with the depth and importance of the data collected with these methods. Continued annual monitoring of individuals subject to invasive or semi-invasive research methods is recommended, along with annual reporting and peer-review of results. Likewise, belugas bearing signs of non-research anthropogenic scarring could still be threatened by the activity even though they survived the immediate trauma event, and should continue to be monitored to assess long-term health, reproduction, and survival even after the threat is removed.

While our study details the physical manifestations of anthropogenic trauma, there are other direct consequences to belugas from anthropogenic activities that our findings do not specifically address, including disruption of behaviors such as foraging, navigation, communication (especially between mothers and calves), nursing, and predator detection/avoidance. Documenting the prevalence of non-lethal scarring gives some indication of how frequently CIBW's are coming into contact with some human activities, and provided qualitative information needed to help guide future efforts to quantify disruption of behaviors from

[10]Quakenbush, L., Alaska Dep. Fish Game, 1300 College Road, Fairbanks. Personal commun., Feb. 2020.

anthropogenic activities. In addition, multiple natural and anthropogenic activities may combine to pose threats greater than either alone (e.g., auditory masking from seismic activities may reduce ability to avoid ship strikes; reduction in prey may cause belugas to risk taking fish from nets and become entangled).

In summary, we have documented that injury from anthropogenic activities does occur at lethal and nonlethal levels. With over one-third of the individuals examined bearing signs of confirmed or possible anthropogenic trauma, these levels are not inconsequential. Although our sample does not allow us to reliably infer the rate of anthropogenic trauma at the population level, it provides an important index of the types and level of trauma experienced by a subset of the population. We found no evidence that unauthorized take from the anthropogenic trauma sources we examined are the primary threat to beluga recovery. However, the evidence we present here suggests anthropogenic trauma remains at least an important component of "cumulative effects," which were ranked as the threat of highest concern in the CIBW Recovery Plan[1].

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The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

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Manuscripts must be double-spaced throughout, and a complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

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The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (2008 ed.) and the Scientific Style and Format: the CSE Manual for Authors, Editors, and Publishers (2014, 8th ed.) published by the Council of Science Editors.for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 November 2013. Measurements should be expressed in metric units, e.g., metric tons as (t); other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g. ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lower-case el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g., nine fish but 9 mm).

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